EXPERIMENTAL SURGERY.

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PUBLISHER'S ANNOUNCEMENT.

For a number of years the author has carried on experimental surgical work with a view to stimulate others to work in the same direction, as experimental research is one of the most important factors in solving scientific problems. As a necessary complement to clinical observation, it tends to purify science from the sterile *a priori* reasons and theories with which medical science has in former times been heavily loaded down.

The different parts of the volume have been published from time to time in the Transactions of the American Surgical Association, and in periodicals not readily accessible to the majority of the medical profession. It has therefore been deemed desirable to bring together in one volume the work done by the author in this direction, in the hope that the practical surgeon of to-day may obtain from it aid in cases which he may at any time meet, that the general practitioner may be guided by it in diagnosis, and that the medical student may learn from its pages how to treat questions according to the methods and laws of true science.

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EXPERIMENTAL SURGERY.

FRACTURES OF THE NECK OF THE FEMUR, WITH SPECIAL REFERENCE TO BONY UNION AFTER INTRA-CAPSULAR FRACTURE.[1]

I. Experiments on Animals.

These experiments were undertaken with a view of obtaining information concerning the following questions: 1. What is the mode of repair after non-impacted intra-capsular fracture of the neck of the femur? 2. What becomes of a bone or metallic nail when driven into the neck of the femur and retained permanently? 3. What is the effect of such a nail upon the adjacent bone tissue? 4. Can we, in cases of intra-capsular fractures of the neck of the femur, by immediate or direct measures, as by nailing the fragments together, obtain such accurate coaptation and retention as to secure union by bone?

A great many difficulties were encountered in performing these experiments, prominent among which were shortness of the femoral neck, difficulty in carrying out the antiseptic treatment, and in providing additional means for securing immobility of the fractured bone, and the great danger to life in using anæsthetics. After I had lost a number of animals from the administration of chloroform and sulphuric ether, I relied exclusively on hypodermic injections of morphia for preventing pain during the operation. The experiments were made on cats, dogs, and rabbits, embracing in all thirty-three

[1] Transactions of the American Surgical Association, vol. 1, 1883.

operations upon thirty animals. In the first thirteen operations the capsule of the hip-joint was exposed by a small posterior incision, and the neck was rendered more accessible by forcibly rotating the thigh inward; the bone was perforated a sufficient number of times with a small drill close to the head, and usually fractured by forcible abduction and rotation outward of the limb. The fracture usually took place with a distinct snap, and was followed by all the characteristic symptoms of fracture through the neck; preternatural mobility, shortening, and crepitus. The incision was closed with catgut sutures, and the wound covered with iodoform and salicylated cotton. In all of these cases the fractured bone was replaced as nearly as possible in the normal position, and a plaster-of-paris dressing applied, which included the pelvis and both extremities. Two of these animals died of pyæmia, and in not a single instance out of the whole number could the slightest attempt at bony union be found at the post-mortem examination. In one instance (a young Newfoundland dog) the hip-joint presented evidences of severe inflammation without suppuration; the head of the femur, having necrosed, was found completely detached in the acetabulum. In some cases ligamentous union had taken place, while in others the fractured surfaces were covered with healthy granulations. In all the specimens the lower fragment had become shortened.

Having satisfied myself that antiseptic treatment could not be followed with sufficient accuracy in these cases to protect the animals against infection, I determined to fracture the neck subcutaneously. In the next six cases, after shaving and disinfecting the hip, rotating the thigh inward and sliding the skin forward, I made a puncture down to the neck of the femur from behind with a narrow tenotome and, inserting the drill into the passage made, divided and fractured the neck as before. The retracting of the skin made the operation entirely subcutaneous. A plaster-of-paris dressing was applied in the same manner as in the first series of experiments. No inflammation or febrile reaction followed these operations, and the post-mortem examinations showed evidence of ligamentous repair. In the absence of bony union, the functional result in several cases appeared remarkable. With few exceptions, all of the fractures so far produced were proved at the post-mortem examinations to be purely intra-capsular.

In experiment No. 21 the neck was fractured subcutaneously

and no retaining dressing applied. The animal was killed five weeks after the operation, and an examination of the hip-joint showed that a firm and short ligamentous union had taken place. After the first three weeks little or no lameness could be detected.

Having failed in all these cases in obtaining union by bone, I determined to secure immediate and direct coaptation by nailing the fragments together.

The fracture was produced subcutaneously in the same way as in the preceding series of cases and, after replacing the limb in its natural position and sliding the opening in the skin to a point corresponding with the centre of the base of the femoral neck, the drill was introduced, and a perforation made in the direction of the centre of the femoral head, and a wire-nail or bone-peg of proper length driven into the opening made by the drill, so that the outer extremity of the nail should not project beyond the surface of the bone.

The first two animals progressed very favorably after the operation and appeared to suffer but little pain, but unfortunately they escaped before an examination could be made to ascertain the results.

Experiment 24. Young cat. Fractured the right femoral neck subcutaneously, and nailed the fragments with a bone-nail. Animal killed ten weeks after operation. Neck of femur almost entirely absorbed; capsular ligament thickened; vertical section through head, neck, and upper portion of shaft showed that the head was almost in contact with the trochanteric portion of the femur; posterior portion of neck showed line of fracture near the head, and fractured surfaces in close contact, but movable upon each other; anterior portion firmly united by a dense compact callus, the upper fragment apparently impacted into the lower; no trace of the bone-peg could be found. The perforation in the trochanter major could be followed to a distance of about 2 mm. In this specimen the lower fragment appeared to have become almost completely absorbed, as the upper fragment remained unchanged, and appeared to be almost in direct contact with the trochanteric portion of the femur. Ligamentum teres normal.

Experiment 25. Adult cat; subcutaneous fracture of neck of right femur; direct transfixion of fragments with wire-nail. Animal killed eighteen weeks after operation. Fracture within capsule close to the head; fragments in close contact, slightly movable upon each other, but united by a very short ligament. Nail had slipped outward, and projected from the trochanteric surface about one-third of an inch, and could be felt as a sharp point immediately under the skin. The projecting portion of the nail was invested by a firm, dense, fibrous capsule, while the implanted portion was firmly and immovably fixed in the bone. Vertical section through the head, neck, and

trochanteric portion showed that almost the entire neck had disappeared by interstitial absorption, the upper fragment being almost in contact with the trochanteric portion. The trochanteric portion had almost entirely lost its cancellated structure, its interior being filled with compact tissue; this change was conspicuous more particularly in that portion traversed by the nail. Capsular ligament thickened; ligamentum teres normal.

Experiment 26. Adult, large Maltese cat; subcutaneous fracture of right femoral neck; direct coaptation of fragments with wire-nail. Animal killed ten weeks after operation. Neck of femur shortened; capsular ligament thickened; ligamentum teres normal; vertical section through the upper portion of the femur showed line of fracture within capsule, with impaction of upper fragment into lower; fragments movable upon each other, but broken surfaces in immediate contact. A new compact layer of bone was formed on the outer surface of the compacta in the region of the lesser trochanter. Nail firmly imbedded in bone, outer extremity on a level with compact layer of trochanter major; it was seen to traverse the trochanteric portion in a backward direction, entering the cavity of the hip-joint, and being in close contact with the posterior surface of the femoral neck, its sharp point being on a level with the highest point of the head. No inflammation in the hip-joint. During life the function of the joint appeared to be perfect. As the point of the nail was firmly fixed in the capsular ligament, and impaction had taken place during the nailing process, immobility was tolerably well attained, and there is every reason to believe that bony union would ultimately have taken place.

Experiment 27. Adult Maltese cat; subcutaneous fracture of left femoral neck; fixation of fragments by means of bone-peg made from compacta of tibia of an ox. Animal killed fourteen weeks after operation. Neck of femur only slightly shortened; capsular ligament nearly normal; ligamentum teres normal; vertical section showed a slight curve in the upper portion of the neck, the head being slightly depressed. Perfect and complete bony union, the spongiosa being restored nearly to its normal condition. Bone-peg had disappeared completely.

Experiment 28. Old Maltese cat; subcutaneous fracture of left femoral neck; direct adjustment of fragments by bone-peg. Cat died of fatty degeneration of liver and kidneys five weeks after operation. Vertical section through upper portion of femur revealed line of fracture partly within and partly without the capsule; no union; fragments in good apposition; outer extremity of bone-nail beneath the compacta; direction of nail downward and inward, the point terminating a little beyond the line of fracture in the lower portion of the neck. The saw had divided the nail obliquely at the juncture of the outer with the middle third. No evidences of inflammation or repair.

Experiment 29. Adult cat; fractured neck of left femur subcutaneously, and used bone-peg for nailing fragments together. Animal died of pyæmia twelve days after operation. Hip-joint filled with pus; fracture intra-capsular; outer extremity of nail on a level with compacta, its point in the cavity of the joint on a level with the foveola of the head. A piece of the posterior

portion of the head was split off, an accident which occurred either by the drill or driving in of the nail.

Experiment 30. Adult cat; subcutaneous fracture of right femoral neck; direct transfixion of fragments by wire-nail. Animal died of pneumonia four weeks after operation. No inflammation of joint; fracture intra-capsular; fragments slightly separated but well transfixed by nail; no callus.

Experiment 31. Young cat; subcutaneous fracture of neck of right femur; direct fixation of fragments with bone-peg. Animal killed four months after operation. During life function of the joint was perfect; vertical section through the head, neck, and upper portion of the shaft, showed that the line of fracture must have been entirely within the capsule, as no thickening of bone or ligament could be seen; capsular ligament normal. Accurate measurement showed only an appreciable shortening of neck; compact tissue within neck more abundant than in the opposite bone. Spongiosa restored to nearly its natural perfection. No trace of track of perforation or bone-nail.

In no case did I feel crepitation more perfectly than in this case, and the sudden giving way of the bone the moment it was fractured was well-marked, and heard by several witnesses. As the post-mortem examination showed a most perfect restoration of the continuity of the bone, I am convinced that this case represents a typical and perfect recovery of union by bone after intra-capsular fracture of the neck of the femur.

In all cases, twenty-one in number, where no direct means of fixation were used, there was not the slightest evidence of bony union, the best result attained being a short ligamentous band. In experiment No. 21, no retention dressing was applied, and the result was equally good, if not better, than in the cases where the plaster-of-paris dressing was used.

In all of these cases the tendency to shortening was not as well marked as in man, while eversion occurred seldom and only to a slight degree. The weight of the limb evidently counteracted muscular action, while the conditions which produce eversion in man were absent in animals. The results obtained by immediate transfixion of the fragments stand in direct contrast to those treated by external fixation. Bony union, or union by short ligament, was the rule, non-union the exception.

These experiments would also tend to prove that aseptic metallic nails, when implanted subcutaneously into living bone, remain firmly in its substance for an indefinite period of time without giving rise to suppuration. And from one of the experiments it will be seen that the point of the nail was within the cavity of the joint for many

weeks without materially interfering with the normal function of the joint, or producing more than a slight synovitis.

Iron- and bone-nails, if driven into living bone, produce osteoplastic inflammation, and are, on this account, not only useful in the treatment of pseud-arthrosis, but are equally beneficial in accelerating the reparative process in recent fractures. Bone-nails are completely absorbed, the time required for absorption to take place depending upon the vascularity of the tissues which are in immediate contact with the nail.

According to Gurlt, the time required for bony union to take place is proportionate to the diameter of the fractured bone, being much shorter in case of slender bones than in those of greater diameter. It appears that in cats the shortest time for the slender neck of the femur to unite by bone is at least two months; hence in man the time required for bony consolidation of fracture of the femoral neck must be at least from one hundred to one hundred and twenty days. As in two of the specimens, well-marked impaction occurred during the nailing process, the question arises: Could not the same desirable conditions be obtained in man by using sufficient lateral force at the time direct coaptation is attempted? In other words: Would it not be prudent to use sufficient force to produce artificial impaction?

In nearly all the specimens the upper fragment underwent but little change, while the lower fragment always, without exception, suffered a diminution in length from osteo-porotic inflammation and interstitial absorption.

Interstitial absorption, as the consequence of inflammatory osteo-porosis, takes place to a greater or less extent in every case of fracture through the femoral neck, and precedes and accompanies the reparative process. In all cases of bony union the posterior attachment of the cervical portion of the capsular ligament was displaced outward, an occurrence which can only be explained satisfactorily by assuming that during the osteo-porotic inflammation, the periosteal investment of the femoral neck is loosened and transplanted toward the femoral shaft, carrying with it the femoral insertion of the capsular ligament. These experiments also illustrate the difficulty of transfixing the upper fragment in the process of nailing; a circumstance largely due to the diminutive size of the bone, the incomplete anæsthesia, and the want of fixation of the parts in their relative normal positions previous to the operation.

II. Bony Union after Impacted Intra-Capsular Fracture of the Neck of the Femur.

At a previous meeting of the American Surgical Association,[1] I presented a specimen of bony union after an intra-capsular fracture of the neck of the femur, and gave a full description of the case and specimen. In the discussion which followed, it became not only evident that, in the opinion of the speakers, the specimen was not what I had claimed for it, but that such a favorable occur-

FIG. 1. Bony Union after Intra-Capsular Fracture. (Anterior view.)
a. Line of Fracture. *b.* Capsular Ligament.

rence was not possible, and that a well-authenticated case had never been observed. These criticisms induced me to look up the literature of the subject with care and impartiality, and to resort to experiment to verify my position.

Case. The patient was a female, aged seventy-five years, and was under my observation at the Milwaukee Hospital. She was in good health at the

[1] Transactions American Surgical Association, 1882.

time of the accident, hence there can be no possibility that the extensive changes in the neck of the femur were the result of senile coxitis or interstitial absorption. The fracture was produced by direct violence by a fall upon the greater trochanter. Fractures of the neck produced in this manner are very apt to be impacted. Loss of function was complete immediately after the injury, and remained so for several months. The patient suffered great pain in the groin and the region of the trochanter minor, a symptom which is always indicative of injury within the capsular ligament. For the purpose of excluding asymmetry of the bones, all the long bones of both legs were

FIG. 2. Bony Union after Intra-Capsular Fracture. (Posterior view.)
a. Capsular Ligament.

measured separately, and on comparing the measurements the injured limb was found shortened half an inch. The limb was strongly everted. Gentle traction had no effect on the length of the limb. On comparing the movements of the trochanter major on both sides by rotating the limbs, it was found that the neck of the femur on the affected side was perceptibly shorter. No crepitation could be felt. As the impaction appeared to be firm no treatment was employed, except rest in bed on a smooth even mattress, the limb being supported on each side with sand-bags. In this position the patient remained for three months; at the expiration of this time she was allowed to walk on crutches. After the third week the shortening gradually increased

until it reached an inch and a half, when the treatment was suspended. The secondary shortening I attributed to inflammatory osteo-porosis and interstitial absorption in the lower fragment. The patient eventually was able to walk quite well with the aid of a cane. Two years after the accident she died of pneumonia. The post-mortem appearances were as follows:

The capsule of the joint, especially the upper portion, was thickened and firm, and bridges of fibrous bands connected the line of fracture with the anterior portion of the ligament. On the anterior surface of the neck the

a

Fig. 3. Bony Union after Intra-Capsular Fracture. (Vertical section.)
a. Compact Plate of Bone.

direction of the fracture could be clearly traced from below upward, and from within outward, but it did not extend beyond the insertion of the capsular ligament. The line of fracture was elevated, and presented a serrated appearance. Posteriorly the head of the bone was in close proximity to the posterior inter-trochanteric ridge. A slight depression on the articular cartilage marked the point of contact with the inner surface of the capsular ligament. Impaction had evidently taken place at the expense of the

posterior compact portion of the neck. A portion of Adams' arch, which had been implanted into the lower fragment, could be distinctly seen in the spongiosa, on making a vertical section (Figs. 1, 2, 3).

A vertical section through the neck, head, and trochanter revealed a white line of very compact bone traversing the cancellous tissue of the neck near the shaft in an oblique direction, corresponding to the line of fracture on the anterior surface of the neck. The anterior half of the specimen was submitted to the boiling test without affecting the union of the fragments, hence there could be no doubt as to the union by bone. The bone outside of the capsular ligament presented no sign of callus or any other evidences of injury or disease.

III. Anatomy of the Neck of the Femur.

The neck of the femur is that portion of the upper extremity of the bone located between the head and trochanters. It is a continuation of the shaft, and springs from an oblong rhomboidal surface from the inner side of the trochanteric region, and is directed obliquely upward, inward, and a little forward. Its base is limited anteriorly and posteriorly by the inter-trochanteric lines; above and behind it reaches the summit of the greater trochanter, while below and in front it extends to the upper margin of the lesser trochanter. In animals the neck of the femur is exceedingly short, and usually set almost at a right angle with the shaft. The great length and obliquity of the neck is peculiar to man. It is this which gives elasticity, freedom and grace to the motions of the body, but at the same time its great length increases the liability to fracture. The decided inclination of the neck forward naturally turns the lower limb a little outward, and constitutes an important determining element in the production of posterior impaction and eversion of the limb in case of fracture.

The length and obliquity of the neck vary at different ages and under different circumstances, in harmony with the requirements of age or conditions. In children it is very oblique, short, and slender, and the bony prominences about the hip are not well defined. As old age advances, the neck in some instances undergoes remarkable changes in structure, contour, and direction: its obliquity in many instances diminishes to such an extent that the head descends below the level of the superior border of the greater trochanter, and at the same time its length is greatly diminished. During adult life, when the femur represents the most perfect degree of development and maximum power of resistance, the neck forms an obtuse angle with

the shaft varying in degree from 120° to 130°.[1] Viewed from the front or from behind, it is seen that the neck is widest at its base or trochanteric portion, gradually becoming narrower until its most contracted part is reached near the head, when it abruptly expands into the corona of the head. The posterior surface is smooth for the play of muscles, especially the obturator externus; convex in the vertical and concave in the longitudinal direction.

The anterior surface is rough, flat from above downward, and slightly concave from without inward. On account of the direction of the neck forward the anterior surface is somewhat shorter than the posterior. According to Heppner this difference amounts to two or two and a half lines.[2] The under surface is smooth, and forms with the inner side of the shaft a well-marked curve or arch nearly three inches in length; the upper surface is rough and only half the length of the lower.

The thin compact layer of bone on the anterior and upper surface is perforated by numerous foramina for the passage of nutrient vessels. Seen from above, the neck appears much narrower than from an anterior or posterior view. The proportion of the diameter of the neck from above downwards, and from before backwards, at the trochanteric portion, is as two to one.

From the general anatomical description, it becomes apparent that the neck of the femur is constructed strictly on purely mechanical principles, in order to resist the greatest amount of vertical pressure; but this becomes more evident if we study the inner architecture of the upper portion of the femur, and more particularly the neck. On making a vertical section through the head, neck, and upper part of the shaft of the femur, it may be seen that the thick compact layer of the shaft, as it approaches the trochanteric region, gives off from its inner surface cancelli at regular intervals, which build up the interior or spongy tissue of the bone. As the spongy tissue is formed at the expense of the compact layer, the latter gradually becomes thinner as it approaches the head, which it supplies with a delicate layer of uniform thickness.

The most important part of the cortical layer in relation to

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[1] Fr. Merkel, Betrachtungen über das os femur. Virchow's Archiv f. Pathol. Anat. Band 50, Heft. II.

[2] C. L. Heppner, Beobachtungen u. Untersuchungen über eingekeilte Schenkelhalsbrueche. Med. Jahrb. Band XVIII, p. 106.

fractures of the neck, is the lower and inner portion, which, from the support it gives to the head and neck, has been called the Adams arch, or femoral brace. It is a continuation of the cortical layer of the inner portion of the shaft, preserving its thickness and strength to a level with the upper margin of the trochanter minor, where it is gradually broken up into spongy tissue, until at the corona it is lost in the thin cortical layer surrounding the head. The trochanter major is surrounded by a thin layer of compact tissue. Transverse sections made through the neck at different depths show that while the anterior and posterior layers are of the same thickness in the upper part of the neck, the posterior wall gradually loses in thickness, until near the lower surface it is reduced to the thinness of paper, while the anterior wall becomes of great thickness and strength.[1] The direction of the neck, the concavity of the posterior surface, and the thinness of the posterior compact wall as compared with the anterior, afford abundant and satisfactory explanations concerning the frequency of posterior impaction in fractures of the neck, and outward rotation of the limb in the non-impacted form.

Of great interest to the surgeon is the arrangement of the cancelli of the spongy tissue in the upper part of the femur. It is true that some of the peculiarities of the structure of the spongiosa in this locality were known to surgeons for a long time, still the credit is due to H. Meyer of having first, in 1867, called attention to the regularity of its construction, and out of this deduced distinct and positive laws governing its mechanical construction.[2]

He describes three distinct systems of cancelli which traverse the neck in different directions. The first begins on a level with the lesser trochanter, and reaches in parallel curves the lower segment of the head of the femur. The second system commences on the opposite side on the same level, and traverses towards the outer side of the trochanter major, and in such a way that the points of intersection of the curves form a series of arches. The third system, which springs from the commencement of the femoral brace, and extends to the upper and inner circumference of the head of the femur, is the strongest, and transfers the weight of the body at once

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[1] H. J. Bigelow, M. D., The True Neck of the Femur, its Structure and Pathology. Boston Med. and Surg. Journ., Jan. 7, 1875.

[2] H. Meyer, Die Architectur der Spongiosa, Archiv f. Anatomie, von Reichert und Du Bois-Reymond, 1867, p. 624.

upon the femoral brace on the inner and lower side of the neck. According to Meyer's description and drawings, a triangle exists between the curves of the first and second systems, the apex of which corresponds to the base of the neck. This triangular space is occupied by an irregular network of cancellated tissue, or by curves from the second or third system. This space, however, does

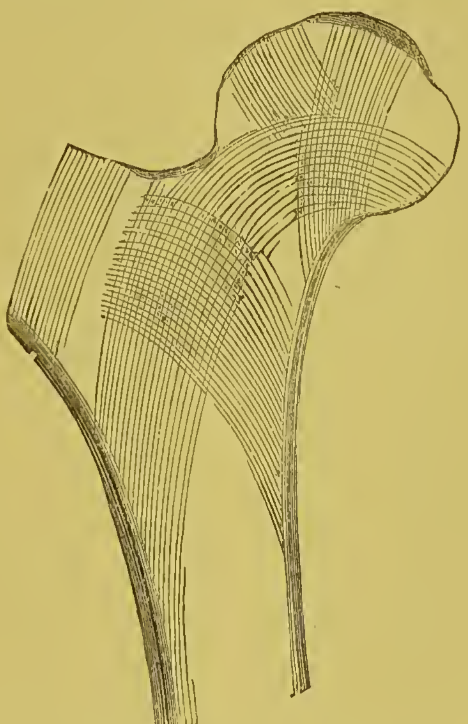

FIG. 4. Meyer's Pressure and Traction Curves. (Meyer.)

not exist in all specimens, but is usually present in the bones of aged people, where the spongiosa has undergone rarefaction.

In specimens from adults the interior of the bone is filled with arches from the inner and outer compact layers for some distance below the point indicated by Meyer. In another paper[1] Meyer dwells at length on the mechanical function of these curves, which he calls pressure and traction curves. It seems as though the compact layer is gradually lost in the spongiosa. This is well seen in a horizontal section through the long bones, more especially of the lower extremity. The lamellæ are so arranged as to correspond to

[1] Die Statik u. Mechanik des menschlichen Knochengerüstes, 1873.

pressure and traction curves, a construction by which the least possible amount of bone tissue can resist the greatest amount of force. The spaces between these curves are filled with loose cancellated tissue, which does not add materially to the strength of the bone, but serves more the purpose of forming a framework for the medullary tissue. The spongiosa appears, therefore, as the primary typical structure of bone, and the compact tissue as an accidental modification of the spongiosa constructed by local concentration of resistance curves.

Heppner divides the cancelli of the spongiosa into two strong and two less dense portions. Among the first he includes the fibres connecting the neck of the femur with the femoral brace, and from the other side extending to the base of the femoral neck. To the second portion belong the fibres in the space between the first two portions and those of the trochanter major.

About the same time that Meyer was investigating this subject, Dr. J. H. Packard published a very interesting paper on "Fractures of the Neck of the Femur,"[1] in which he called attention to the architecture of the interior of the neck of the femur, and accurately described and delineated the arching fibres passing from the femoral brace to the upper segment of the head of the femur. He says: "A careful examination of vertical sections of the head and neck of the femur shows, as several writers have pointed out, that a number of the cancellous columns, beginning at the upper end of the inner wall of the shaft of the bone, diverge upward to the concavity of the thin articular lamella of compact substances of the head, so as to receive the weight of the body upon their extremities. Another series of columns are found to run outward from the same point, and from a line running upward from it, to meet other columns running up inward from the outer wall of the shaft; and these two sets of columns form a series of groined arches culminating at the upper wall of the neck of the bone, a little to the inner side of the greater trochanter.

"By this arrangement the shifting of the weight towards the outer or upper portion of the head of the bone is provided for, the pressure coming in greater degree on the outer wall of the shaft, the inner wall, however, receiving its share through the inner columns

[1] On some Points relating to Fractures of the Neck of the Femur, by John H. Packard, M.D., Amer. Journ. of Med. Sciences, Oct., 1867, p. 379.

of the arches. The remainder of the cancelli run in various directions, not capriciously or at random, but so as to afford in the aggregate a very strong support to the solid wall of the bone. Sometimes it may be clearly seen that they are so placed as to run as nearly as possible in the line of muscular traction; an arrangement, the mechanical advantage of which must be at once evident."

In 1870, Julius Wolff[1] published the result of his studies of the spongiosa, which he considered as standing in the closest relation to the static and dynamic forces of the bones. In his researches he made use of the mathematical calculations of Culmann, showing that interior braces intended to aid in supporting a weight upon the end of a cylinder, curved like the femur, or like a crane or derrick, should be placed, in order to act to advantage, precisely where the trabeculæ of the spongy tissue of this bone actually exist. "Nature," says Wolff, "has built the spongy bones as an engineer would construct a truss bridge, mathematically."

A compact plate of bone (Schenkelsporn, septum) is usually found imbedded in the cancellous tissue of the neck, and to it an important function has been assigned by Merkel and Bigelow. Merkel[2] described a structure in the interior of the neck of the femur which he called "Schenkelsporn." It consists of a wedge-shaped solid projection of the cortical layer, which springs from its inner surface on a level with the trochanter minor towards the median line, and penetrates into the interior of the spongiosa to the depth of 1 cm., and is lost immediately under the head of the femur on the anterior surface of the neck. It is not found in the fœtus, is fully developed in the adult, and again disappears completely during old age.

Bigelow, after describing the necessary manipulations for exposing it, says: "The septum will then be distinctly seen, as a thin dense plate of bone continuous with the back of the neck, and reinforcing it, plunging beneath the inter-trochanteric ridge in an endeavor to reach the opposite and outer side of the shaft. At its lower extremity it curves a little forward, so as to take its origin, when on a level with, from the centre, instead of the back, of the

[1] Julius Wolff, Ueber die innere Architectur der Knochen und ihre Bedeutung für die Frage von Knochenwachsthum. Archiv f. Path. Anat. u. Phys. Band 50.

[2] Der Schenkelsporn. Centralbl. f. d. Med. Wissensch. No. 27, 1873.

cylindrical cavity; a disposition easily seen in a transverse section of the shaft just above the trochanter minor. Or it may be said that the posterior wall of the neck forks before reaching the inter-trochanteric line, one layer being seen upon the surface, while the other dives beneath the inter-trochanteric ridge in a vain attempt to reach the outer wall of the shaft. If these views be correct, the inter-trochanteric ridge is simply a buttress erected for the insertion of muscles upon and over the true neck, by the impaction of which it is in fact often split off and detached in a mass; the force exerted by the true neck, though slight, being nevertheless an effort to resist such impaction."

The importance of this septum, when in a perfect state, becomes evident, as the same author continues: "The true neck is often, at best, but an ineffectual attempt to bridge the interval beneath the trochanters, as seen in Merkel's figures, while, in the latter half of life, it degenerates into papery plates, radiating downward from a point near the lesser trochanter. Weakened in this way, both by its own tenuity and by its own slender union to the trochanteric ridge, the true neck has great practical interest for the surgeon. Even the adult femur is generally defective in construction at this point; and here occurs the most common form of fracture, namely, the posterior impacted fracture of the base of the neck."

Bigelow looks upon the septum as a continuation of the "True Neck," while Merkel has described the same structure as a projection of a portion of the posterior and inner compact wall into the spongiosa; hence, he has called it "Calcar femoral" or "Schenkelsporn." The relation of the septum to the trochanter minor is such as to isolate its spongy tissue, and on that account Wolff alludes to it as "the compact tissue upon which the trochanter minor rests." The importance of this structure in preventing and determining the location of fractures has undoubtedly been over-estimated. It is absent in children, and is subject to the same degenerative changes as the remaining portions of the cortical layer and the spongiosa.

In conclusion, it may be stated that the spongiosa of the upper extremity of the femur is derived directly from, and at the expense of the compact layer; that it is constructed upon a definite plan in a series of arches arranged in such a manner as to resist the greatest amount of vertical pressure according to well-established architectural laws; and at the same time, that by expanding the bone it

furnishes a more extensive surface for muscular attachments, and imparts to it a greater degree of elasticity.

The exact point of insertion of the capsular ligament into the femoral neck has been a frequent source of dispute among anatomists and surgeons in deciding the location of fractures in this locality. Great discrepancies on this point may be found in our anatomical text-books.

To Dr. Geo. K. Smith much credit is due for the light he has thrown on this subject.[1] By injecting the capsule of the hip-joint with air or plaster-of-paris he was enabled to make very careful dissections, and by measuring accurately the distance between the corona of the head and the insertion of the ligament, and from this point to the inter-trochanteric lines, he could locate the exact point of insertion. After preparing and measuring sixty-one specimens in this manner he came to the following important conclusions:

"1. That scarcely any two specimens of the normal capsule, taken from different subjects, are alike in their insertion into the neck of the bone; consequently no definite description of its insertion can be given.

"2. That the normal capsules of the opposite femurs of the same subject are alike in their insertion. Having measured twenty-four pairs I have yet to see a single variation from this rule. Moreover, it is just what we must expect to find in obedience to that law of symmetrical conformation which pervades the animal economy."

Morris[2] locates the femoral insertion of the capsular ligament as follows: "At the femur the capsule is fixed to the anterior portion of the upper border of the great trochanter, and to the tubercle of the femur close to the insertion of the gluteus minimus and the origin of the vastus externus, with slips from each of which it is blended. Thence it runs along the upper and outer part of the anterior inter-trochanteric line, but soon gets below it, and at the inner border of the femur is on the level of the lower surface of the small trochanter. It is then inclined upward and backward along an oblique line, two-thirds of an inch in front of the small trochanter, to reach the back of the neck; here it is attached above the

[1] The Insertion of the Capsular Ligament of the Hip-joint, and its Relation to Intra-capsular Fracture. New York, 1862.

[2] The Anatomy of the Joints of Man. Philadelphia, 1879, p. 322.

posterior inter-trochanteric line at a distance varying from half an inch, at the lower and upper ends, to over two-thirds of an inch opposite the middle of that line. . . . After laying open the capsule it is seen that some of the deeper fibres of this ligament are reflected upward along the neck, so as to be attached to the femur much nearer its head. These reflected fibres occur at three places, one corresponding in position to the middle of the ilio-femoral ligament, another to the pectineo-femoral, and the third on the upper and back part of the neck. A thin fold of synovial membrane stretches between the reflected and the unreflected fibres of the capsule."

These strong bands of reflected fibres have been called retinacula by Weitbrecht. Packard, in his paper previously alluded to, has called attention to the existence of pockets, usually three in number, between the reflected fibres.

Rüdinger,[1] in speaking of the fibrous capsule of the hip-joint, says: "Its attachment to the lateral portions of the neck is in such a manner, that anteriorly it reaches the anterior inter-trochanteric line; posteriorly, on the other hand, it reaches only as far as the middle of the neck."

Practically, we can safely say, that the anterior portion of the capsular ligament, as a rule, is inserted into the anterior inter-trochanteric line, reaching its lowest level on the lower surface of the lesser trochanter, while the posterior portion is usually inserted at or near the middle of the femoral neck. A close inspection of the posterior segment of the capsular ligament will usually reveal the existence of more or less fibres running from the insertion of the ligament proper towards the inter-trochanteric ridge. For our purpose it is also proper to mention that the largest nutrient vessels to the neck pass beneath the reflected portions of the ligament.

The ligamentum teres will receive mention only as far as it serves as a carrier of blood-vessels to the head of the femur. In infants it contains a number of blood-vessels which enter the head of the femur at the point of insertion of the ligament in the fovea. That the blood supply from this source is not essential for the growth and development of the upper extremity of the thigh-bone. is apparent from the fact that it is wanting in many animals. as the

[1] Topographisch-chirurgische Anatomie des Menschen. Stuttgart, 1873, p. 142.

Bradypus, Echidna, Cholaepus, elephant, rhinoceros, and others. According to Savory, two hip-joints were examined at St. Bartholomew's Hospital, in which no trace of this ligament could be found, but the head of the femur presented a depression, not covered with cartilage, at the usual point of insertion of this ligament. There can be no doubt that in infants the vessels of this ligament penetrate the bone and furnish material for ossification to the epiphysis of the femur. After the growth of the bone has been completed, the vessels diminish in size with advancing age, and disappear entirely at their point of entrance into the bone in a certain percentage of cases. Hyrtl has asserted that the vessels from the capsule which pass along the ligamentum teres to the surface of the head do not communicate with the vessels of the medullary substance, but return in the form of loops.

In one-third of the specimens examined by Welcker,[1] no foramina nutritia could be found in the fovea capitis; hence, he concluded that the round ligament is not destined to act as a carrier for nutrient vessels. Sappey, on the other hand, attributes to the ligamentum teres the function of protecting the vessels and nerves that nourish the head of the femur.

Langer[2] has made careful injections of the vessels of the hip-joint, and has observed that not all of the vessels of the ligamentum teres return in loops on reaching the bone, as described by Hyrtl, but that some of them penetrate into the spongiosa of the head of the femur. I have examined a number of specimens with reference to this point, and have been able to detect with the naked eye nutrient foramina in the fovea capitis in more than one-half of them. When the foramina were of considerable size, I have been able to trace them for some distance into the bone. In such specimens there can be no doubt as to the presence of blood-vessels from the round ligament in the interior of the spongy tissue of the head of the femur, where the vessels from the round ligament enter into anastomosis with vessels from the bone, and render material assistance in maintaining the circulation in the head of the femur. In some specimens the foramina may be so small as to elude detection with the naked eye, but may nevertheless admit small vessels which

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[1] Virchow u. Hirsch's Jahresbericht, vol. i, 1875, p. 9.

[2] Rüdinger, op. cit., p. 144.

may be of some importance in furnishing material for nutrition in the bone. The absence or destruction of the vessels of the ligamentum teres may not interfere with the growth and development of the bone as long as the normal supply through the neck of the femur is not impaired; but in case of fracture of the neck they are of great importance, and assume a compensating function in harmony with similar processes in other parts of the body. Rudimentary small vessels may assume vicarious action for the purpose of answering an increased demand, and thus supply a sufficient amount of blood, not only for maintaining the vitality of the upper fragment, but also to furnish material for repair.

IV. Classification of Fractures of the Neck of the Femur.

Since the teachings of Sir Astley Cooper on this subject, it has been customary to classify fractures of the cervix femoris according to the relative position the capsular ligament bears to the seat of fracture, into the intra-capsular and extra-capsular fractures, to which has been added a third variety, fractures partly within and partly without the capsular ligament. The mixed variety has given rise to a good deal of confusion, as some have included it among intra-capsular fractures, while others class it with extra-capsular fractures. Since it has been ascertained that many of the fractures of the neck of the femur are impacted, those who have placed great prognostic and therapeutic importance upon this condition, have made impaction the basis for a new classification, and speak of impacted and non-impacted fractures of the neck of the femur. Among those who favored this classification may be enumerated Cloquet, Josselin, Duplay, Bigelow, Bryant, Hueter, and Lossen.

The distinction into impacted and non-impacted fractures is important in a clinical, diagnostic, prognostic, and therapeutic sense, while the division into intra-capsular and extra-capsular fractures has a very important pathological significance. Fractures of the neck of the femur with impaction will unite by bony union irrespective of the situation of the capsular ligament, provided the impaction is maintained for a sufficient length of time. Fractures, impacted or non-impacted, outside of the capsular ligament will unite in the same manner as fractures in any other locality, if the fractured ends are kept in apposition and immobilized for the necessary length of

time. Fractures at the narrow part of the neck, and entirely within the capsule, can only unite by bone, if the penetration is such as to secure apposition for a number of weeks, or if the same degree of apposition and immobilization is effected by surgical procedures. The frequency with which impaction occurs in the femoral neck, and the important part it performs in the reparative process, entitle it to a permanent place as a basis for classification.

When we are able to diagnosticate the existence of an impacted fracture of the neck of the femur, all efforts to locate the exact seat of fracture are perfectly useless, as it could have no influence in selecting therapeutic measures, and might eventuate disastrously by abolishing the most favorable conditions for a fortunate issue. If we adopt the proposition, that fractures of the femoral neck with penetration can, and often do unite by bone, irrespective of their relative position to the capsular ligament, then the distinction between fractures within and without the capsular ligament can only find a practical application in the examination of specimens to prove or disprove the correctness of the proposition. This holds the more true as, *in vivo*, all known diagnostic means have proved unreliable in locating the exact point of fracture. The sooner the profession can be convinced that intra-capsular fractures also unite by bony union under certain favorable conditions, the better will it be to abandon the old classification, which has proved to be incorrect anatomically, and unwarranted by pathological facts. Practically, then, it is always important so ascertain the presence of impaction, and not to interfere with it when found; theoretically, and for the purpose of adopting therapeutic measures, it is desirable in non-impacted fractures to locate as nearly as possible the seat of fracture without inflicting unnecessary violence.

In the light of recent anatomical investigation and pathological research, and for the purpose of avoiding unnecessary confusion, it would be advisable to limit the term intra-capsular to all fractures that do not extend beyond the insertion of the capsular ligament, and to include among the extra-capsular fractures, the so-called mixed and purely extra-capsular fractures. Remembering the attachment of the anterior portion of the capsular ligament we would naturally infer that purely extra-capsular fractures, without further injury to the shaft of the femur, if possible at all, must be exceedingly rare. The greatest number of extra-capsular fractures,

as described by our text-books, have belonged to the mixed variety; intra-capsular in front, extra-capsular behind. In speaking of extra-capsular fractures, Dr. R. W. Smith says: "All extra-capsular fractures are, in the first instance, also impacted fractures, and all impacted fractures are necessarily accompanied by a fracture traversing some part of the trochanteric region. I have omitted no opportunity of investigating this point, and have now examined here and elsewhere upwards of one hundred specimens of the extra-capsular fracture, and have found in all, without a single exception, a second fracture traversing some portion of the inter-trochanteric space."

In commenting on the paper of Dr. G. K. Smith,[1] Dr. Post suggested to substitute for intra-capsular and extra-capsular, the terms intra-cervical and extra-cervical; the latter designation to indicate an impacted fracture at the base of the neck with more or less injury of the femoral shaft. As under this classification intra-cervical fractures would include intra-capsular and mixed fractures, and the term extra-cervical would imply the existence of a fracture rather beyond than in the cervix itself, these terms are not of sufficiently accurate anatomico-pathological precision to recommend themselves for general adoption, although they are full of practical significance. Inasmuch as the principal object in writing this article has been to prove that bony union after intra-capsular fractures can take place, the terms intra-capsular and extra-capsular have been retained, but will be applied in the sense previously suggested.

V. Relative Number of Intra- and Extra-Capsular Fractures.

The inability to accurately locate the fracture during life, and the existing confusion and uncertainty as to the meaning and application of the terms intra- and extra-capsular in the description of specimens have rendered the statistics on this point unsatisfactory and unreliable. Although the cervix femoris may be broken at any point between the head of the femur and the inter-trochanteric ridges, there are certain points where it is more liable to give way. The exact location of the fracture is determined to a great extent by the seat and degree of senile osteo-porosis, and the direction of the fracturing force. Senile osteo-porosis, as we have seen, begins in

[1] Op. cit., p. 35.

the spongiosa, and reaches its maximum degree soonest at the contracted portion of the neck; hence fracture nearest the head is most likely to take place in decrepit old people. Fractures at this point are exceedingly rare in persons less than fifty years of age, only a very few well-authenticated cases being on record.

Rodet, in a series of experiments on the femur and on plaster-of-paris casts of the upper extremity of this bone, has demonstrated the important fact, that the situation and direction of a fracture of the neck of the femur may be predicted to almost a certainty, by a knowledge of the direction in which the force was applied. Thus, a force acting vertically will produce an oblique intra-capsular fracture; a force acting from before backward, a transverse intra-capsular fracture; one from behind forward, a fracture partly within and partly without the capsule; and a force applied transversely, a fracture entirely without the capsule. Clinical evidence has repeatedly verified the correctness of these observations. The traction fractures described by Linhart, Riedinger, and Hueter, from the powerful traction of the ilio-femoral ligament, when the thigh is over-extended and adducted, invariably fall outside of the limits of the capsule.

Bonnet believed that the line of fracture was almost always without the capsule, and Nélaton contended that in the great majority of cases he made the same observation; while many authors, equally competent, among them Sir Astley Cooper, Ashhurst, and Druitt, claim that intra-capsular fracture occurs more frequently in persons above fifty years of age. Of twelve specimens examined in the museum of St. Bartholomew's Hospital by Stanley, six were supposed to be intra-capsular, and six extra-capsular.

Malgaigne[1] examined one hundred and three specimens from different sources to determine the relative frequency of these fractures, and found that sixty-one belonged to the intra-capsular to forty-two of the extra-capsular variety.

M. Mercier, at Bicêtre, found in eight autopsies three intra-capsular and four extra-capsular fractures, and one below the trochanters; while Malgaigne himself, in the same hospital, found in eight other autopsies one fracture below the trochanters, five within the capsule, and only two outside of it. Stimson[2] made a post-mor-

[1] Treatise on Fractures. Translated by J. H. Packard, M.D., 1859, p. 533.

[2] A Treatise on Fractures, 1883, p. 491.

tem examination in six cases, and ascertained that in two of them the fracture was purely intra-capsular, and that in four, the fracture was at the junction of the neck and shaft.

Heppner[1] gives a description of five cases of impacted fracture of the neck of the femur, of which number three were extra-capsular and two intra-capsular. Of twenty-three specimens of fracture of the neck of the femur, in the Museums of the College of Physicians, Philadelphia, and the University of Pennsylvania, examined by Agnew,[2] ten were within and thirteen without the capsular ligament. Mussey's collection contains twelve examples of fracture of the femur without, and ten within the capsule.

The above statistics embrace one hundred and eighty-five post-mortem specimens, of which number ninety-nine were fractures within, and eighty-six without the capsular ligament; figures which would tend to prove that intra-capsular fractures are more frequent than fractures without the capsule. It must, however, be remembered that many of these specimens were collected for a special purpose, and on that account the numbers do not represent the true proportion as it actually exists. If the statistics obtained by the examination of post-mortem specimens are not reliable in ascertaining the relative frequency with which these fractures occur, the information derived from clinical observation must prove still less satisfactory in deciding this question, as the symptoms during life are not sufficiently well marked to enable the surgeon to locate with certainty the exact seat of fracture.

Billroth[3] refers to twenty-seven cases of fracture of the neck of the femur, of which number thirteen were diagnosticated as intra-capsular, and fourteen extra-capsular. In Dr. Hyde's table of three hundred and twenty-one cases of fracture of the femur, we find that the neck was involved thirty-one times; these were supposed to be located fourteen times within and seventeen times without the capsule.

Hamilton[4] has recorded eighty-four cases of fracture of the femoral neck from his own personal observation; of these, forty were

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[1] Beobachtungen u. Untersuchungen über die Schenkelhalsbrueche. Oestr. Med. Jahrb. Heft. 3 u. 4, 1870.

[2] Principles and Practice of Surgery, vol. i., 1878, p. 931.

[3] Chirurgische Klinik. Wien, 1879.

[4] A Practical Treatise on Fractures and Dislocations, 1880, p. 393.

believed to be without the capsule, and thirty were believed to be within, the remainder were undetermined. These statistics furnish one hundred and twenty-eight cases with fifty-seven intra-capsular, and seventy-one extra-capsular fractures, a majority in favor of the extra-capsular variety.

Combining the figures from the museum specimens and those taken from bedside observation we obtain three hundred and thirteen cases of fracture of the neck of the femur, of which number one hundred and fifty-six were supposed to be located within, and one hundred and fifty-seven without the capsular ligament.

VI. Incomplete Fractures of the Neck of the Femur.

The structure of the neck of the femur in the aged furnishes conditions unusually favorable for the occurrence of partial or incomplete fracture. Although this form of fracture has received but little attention on the part of surgical writers, receiving at the best only brief mention, it would appear from the cases reported during the last few years, that the accident is not as rare as has been supposed. Colles[1] was the first to call attention to this variety of fracture as it occurs in the neck of the femur, and described three cases. Dr. J. B. S. Jackson, of Boston, described a case of incomplete fracture (fissure), the line of fracture extending from the junction of the upper border of the neck with the head downward to within a quarter of an inch of the inferior and internal wall of the bone.

Gurlt[2] mentions three cases. In Tournel's case the infraction took place at the upper portion of the base of the neck, the line of fracture running from the digital fossa downward. In the case reported by P. Wilkinson King, the line of fracture was near the head of the femur, a bridge of compact tissue on the anterior and upper portion of the neck, one-third the circumference of the compacta remaining intact. The third described he found in the Pathological Museum in Giessen. The transverse infraction affected the entire posterior half of the femoral neck about its middle, while the anterior wall was not affected. The margins of the fractured surfaces were in immediate contact.

[1] Dublin Hospital Reports, vol. ii.

[2] Knochenbruecche, vol. i, p. 31.

Koenig[1] described two specimens. In the first specimen the line of fracture occurred on the upper and posterior surface of the neck, near the head, with impaction of the cervical portion into the head, while the compact tissue on the anterior and inferior surface remained entire. In the second specimen, the line of infraction took place at the lower surface of the neck, at the most constricted portion, with penetration of the apex of Adams' arch into the interior of the head, while the upper portion of the neck had yielded without being broken. (Figs. 5 and 6.)

These two varieties Koenig considers as representing typical forms of this fracture, the mechanism of their production being the same as in complete fractures of the neck. In the first variety, from the direction of the impaction the limb is rotated outward, while in the second form the foot remains in its natural position, but the limb is shortened in proportion to the extent of the impaction. Koenig is of the opinion that many of the cases of complete recovery after supposed intra-capsular fractures, were cases of incomplete fracture with impaction. At the same meeting, Billroth reported two cases where he made the diagnosis of incomplete fracture during life; in both instances recovery was imperfect.

Incomplete fractures of the neck of the femur, as well as of other bones, consist of a loss of continuity of a certain number of cancelli, forming the substance of bone. It may exist in every degree, from a fracture almost complete to one in which the number of severed cancelli is so small as to elude detection by the naked eye. The location and direction of the line of infraction, as in complete fractures, must necessarily vary according to the direction in which the force is applied which produces the fracture. Stimson[2] says: "The line of fracture is transverse and upon the concave side, and is produced by crushing, not by overbending." Incomplete fractures are repaired by the formation of intermediate callus between the fractured surfaces, which restores the continuity of the bone. The unbroken portions of the bone and periosteum serve as a perfect splint, which secures complete rest and apposition until the injury is repaired. The deformity attending this accident is necessarily always very slight, and as the symptoms at the same time are not

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[1] Verhandlungen der Deutschen Gesellschaft f. Chirurgie, 1877. p. 131.

[2] A Treatise on Fractures, 1883, p. 41.

pronounced, the diagnosis must always remain uncertain. The cases are most likely to be mistaken for contusion of the hip; hence, we should always examine the severer injuries about the hip with unusual care, and if any doubt exists, give the patient the benefit of such doubt, and treat the case as one of incomplete or complete fracture with impaction.

FIG. 5. FIG. 6.
Partial Fracture of Neck of Femur. (Koenig.)

VII. Impacted Fractures of the Neck of the Femur.

Impaction, penetration, implantation, and incuneation, are synonymous terms, which are used to describe a fracture when one fractured end is driven into the other, an occurrence which secures perfect coaptation and fixation. In some instances impaction is mutual. Impaction may be complete or incomplete, according to the tissue-structure at the seat of the fracture, or the direction and intensity of the fracturing force. Impacted fractures are most frequently met with in the spongy portions of the long bones, and in persons suffering from osteo-porosis from any cause. These fractures have only quite recently become the object of special investigation, and are at the present time receiving the attention their importance merits.

Robert was the first to give a good description of impacted

fracture of the neck of the femur, and explain its mechanism. He specified the following conditions which must be present for penetration to take place: In the first place, the penetrating bone must have a conical shape, and must be placed opposite a spongy section of bone, and must have been broken off close to the insertion of the same. The impacting force must be applied in the direction of the long axis of the incuneated bone. All these conditions are presented in fractures through the neck of the femur. Adams regarded the inner and lower compact tissue of the neck of the femur as the principal element of impaction; the direction of the fracture through the neck being oblique from above downward, fractures the arch in such a way that the apex, sharp and pointed, is placed opposite the loosely cancellated tissue of the shaft, into which it is driven by the same force which fractured the bone.

Streubel looked upon senile osteo-porosis as the main cause of impaction. It is necessary, however, that the compacta of the fractured neck retain sufficient firmness to penetrate the bone without being comminuted. Some authors assert that impaction follows fracture in such a way that the neck of the femur gives way to indirect violence from a fall upon the foot or knee, the impaction following by the patient falling upon the trochanter. Heppner assumes that the relation existing between the neck of the femur and the trochanteric portion of the femur is the cause of impaction, and takes into special consideration the spongiosa in which he distinguishes two distinct layers, of which one possesses a greater degree of density than the other. He believes fracture at the base of the neck with impaction is always the result of force applied to the trochanter major, which expends itself at the origin of the femoral brace, and fractures the entire base of the cervix. Aside from the diminution in the obliquity of the cervix, and the presence of senile osteo-porosis, he finds another cause for this fracture in the general atrophy of the aged, rendering the trochanter major more prominent and thus more directly exposed to external violence. The last assertion, however, is not in accord with experience, as corpulent aged females furnish the largest number of fractures of the femoral neck.

Streubel made some experiments on cadavers to determine the seat of fracture on the application of direct and indirect violence. To test the effect of violence applied in the axis of the femur, he

amputated the thigh and applied the force directly to the sawed surface of the femur, and succeeded only in one instance in producing an intra-capsular fracture. By applying the force to the trochanter major he produced one extra-capsular impacted fracture, while in all other cases the trochanter major was fractured. Heppner repeated these experiments with the same results. He then reversed the direction of the force. Taking a femur, stripped of its soft parts, and resting the outer surface of the trochanter major upon a table, he struck the head of the femur with an axe, and produced in every instance a fracture of the neck resembling an impacted fracture. He repeated the experiment thirty times, and in five of the cases the impaction was typical. From these experiments he has drawn the deduction, that the fracture is produced by contre-coup, whether the force is applied to the trochanter major or through the axis of the femur.

In regard to impaction of intra-capsular fractures he could find nothing in the literature on the subject of fractures of the femoral neck. Vollemier speaks of them at length, but only for the purpose of denying their occurrence. But, inasmuch as he states that he has seen several specimens where the end of Adams' arch was found to terminate in the interior of the spongy portion of the head of the femur, he contradicts himself, as the description corresponds with impaction of the lower wall of the femoral arch into the head. The question at issue is not the degree of impaction, but whether it can secure mutual fixation of the fragments. In most cases only the lower edge of the outer fragment is impacted, but the contrary may take place, as is evident from the description given by Koenig under the head of partial fractures.

For one of the best contributions to our knowledge of impacted fractures of the neck of the femur we are indebted to Riedinger.[1] He has studied this subject by experiments and examination of museum specimens. In speaking of intra-capsular fractures, he says that, as a rule, the lower and more particularly the posterior wall of the lower fragment is driven into the spongiosa of the head. As a necessary consequence of this form of impaction, the head of the femur is depressed and inclines backward, sometimes to such an extent as to come in contact with the posterior inter-trochanteric

[1] Studien über Grund und Einkeilung der Schenkelhalsbrucche, Würzburg, 1874.

line. The cortical portion of the lower fragment can often be traced into the interior of the head to a distance of two centimetres. At the anterior line of fracture the denticulated margins retain such a firm grasp as to add materially to the firmness of the impaction. At the base of the neck of the femur the conditions for impaction are most favorable. If sufficient force is applied over the trochanter major, the neck fractures in such a way that the femoral brace is detached near its origin, and constitutes a sharp projection, which, when slightly dislocated, is placed *vis-a-vis* to the spongy tissue of the outer fragment, and is implanted into the same by the fracturing force. The upper portion of the inner fragment, although not possessed of an analagous dense structure as the femoral brace, follows in the penetrating process the more readily, as the whole inner fragment is wedge-shaped. The spongiosa between the cortical layers forms a somewhat sharp projection. Impaction of the base of the neck is carried to its fullest extent in case the fracturing force is sufficient to fracture also the trochanteric portion of the femur. In such instances the apex of the inner fragment sometimes splits the shaft of the femur into a number of fragments, and presents itself on the outer surface of the bone beneath the soft parts.

Mr. Bryant[1] has published a table of fourteen cases of impacted fracture of the neck of the femur, and from an analytical study of these cases he draws the following conclusions:

"1. That in all the cases the injury to the hip-joint was communicated through the greater trochanter.

"2. That, as a result of the injury, there was more or less loss of power in the limb; in some cases it was complete, in as many the patient could rotate the limb slightly on the couch; and in two cases partial flexion of the thigh could be performed.

"3. That in all the cases immediate shortening of the injured limb was the direct result of the accident; and that this shortening was about an inch or less, and it was irremediable by extension.

"4. That the foot of the injured extremity was either straight or slightly everted, although in several cases this eversion was less marked on the injured than on the sound side.

"5. That the great trochanter was placed near the median line

[1] Medical Times and Gazette, April 17 and May 1, 1869.

of the body, and also nearer the anterior superior spinous process of the crest of the ilium than on the sound side.

"6. That the head of the femur could be made to rotate smoothly in the acetabulum, and the great trochanter moved with it.

"7. That crepitus was either absent or indistinct in all cases.

"8. That all the cases, with one exception, occurred in patients past middle age."

Bardeleben[1] maintains that, in intra-capsular fractures, longitudinal displacement is opposed by the untorn portions of the capsular ligament. In this fracture the ends of the fragments are often interlocked in such a manner as to prevent dislocation, and may even enable the patient to walk on the limb for a few hours, or for several days. The more important elements in retaining the fragments are, however, the presence of impaction, and the untorn portions of the reflected capsule, the retinacula of Weitbrecht.

S. D. Gross[2] believes that impaction is rare, and, when present, is almost exclusively extra-capsular. The distance of penetration varies from a few lines to one-half or three-quarters of an inch.

Hueter[3] places great importance in recognizing the presence of impaction. He regards the schenkelsporn as the most important agent in the process of impaction. Anatomically he distinguishes two varieties: either the upper end of the lower fragment is displaced inward, so that the termination of the schenkelsporn penetrates the soft tissues below the upper fragment, or the lower fragment is displaced outward in such a manner that the schenkelsporn is driven into the spongiosa of the neck. Impacted fractures are not so frequent as non-impacted fractures, but they are sufficiently common to render them of the greatest importance in the diagnosis, prognosis, and treatment of fractures of the neck of the femur.

H. H. Smith[4] believes that in the majority of cases the neck of the femur is fractured by indirect violence, impaction following subsequently by a fall upon the trochanter major. R. W. Smith says: "That all extra-capsular fractures are, in the first instance, also impacted fractures."

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[1] Lehrbuch der Chirurgie. Band II, 1871, S. 473.

[2] System of Surgery, vol. i, 1864, p. 965.

[3] Grundriss der Chirurgie. B. II, 1882, S. 883.

[4] The Principles and Practice of Surgery, 1863.

Robert[1] was of the opinion that fractures of the neck of the femur were nearly always impacted, and as such should be disturbed as little as possible to obtain the best results, as the impaction furnished the best possible conditions for bony union to take place. MacNamara[2] affirms that fractures of the neck of the femur are usually impacted, the fragments being jammed into one another; the smashed cancellated tissue must be removed, rendering the process of repair tedious.

Bigelow,[3] who has devoted a great deal of time and attention to the subject of injuries about the hip-joint, is convinced from the

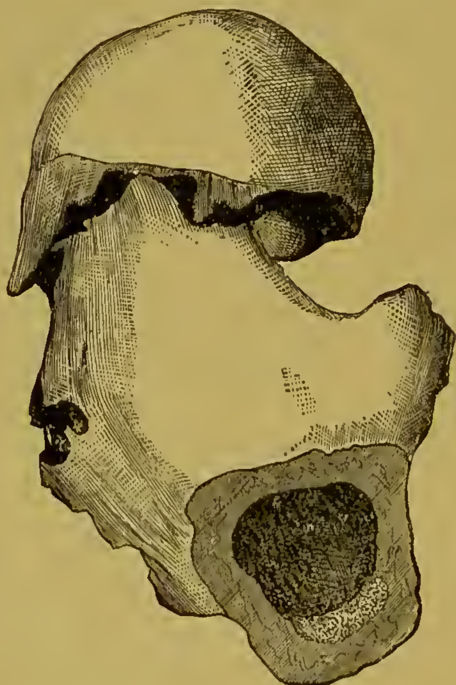

FIG. 7. Posterior Impaction of Femoral Neck. (Bigelow.)

views he entertains as to the architecture of the femoral neck, that fracture takes place most frequently at the base of the neck, and is usually accompanied by impaction of its posterior wall. (Figs. 7 and 8.) These cases present outward rotation of the limb, and slight shortening, and may be followed by complete repair without lameness.

[1] Mémoire sur les Fract. du col de Fémor. 1845.

[2] Diseases of Bones and Joints, 1881.

[3] The True Neck of the Femur, Boston Med. and Surg. Jour., Jan. 7. 1875.

Impaction at the constricted portion of the neck is not frequent. Impaction of the entire base of the neck with inward rotation of the limb is very rare, and is hardly possible without fracture of the trochanters.

The same author, at a meeting of the Boston Society for Medical Improvement, held November 23, 1874, exhibited a specimen of a fracture within the capsular ligament with imperfect

FIG. 8. Posterior Impaction of Femoral Neck. (Bigelow.) Transverse Section.

impaction, which, during life, had simulated impaction at the base of the neck, and induced him to express a favorable prognosis. "The autopsy showed that the fracture was not through the base of the neck, but through the neck itself, close to the head, and that the fragments were 'rabbeted' together. There was motion enough to have worn away the thin walls of the neck, and to show that any bony union, had the patient lived, was not to be hoped for. In this

respect it differed from Dr. Gay's case of impacted fracture into the head, where the patient, on the day of his death from pneumonia, a week or two after the accident, lifted up his leg and said that as far as that went, he was getting well. Had that man lived, he would undoubtedly have had bony union and a serviceable leg. The rabbeting of the fragments was shown here very well in the present specimen. It was due to a conical mass of comparatively dense bony tissue projecting from the head fragment, which was driven into the loose cancellated structure of the portion of the neck in the shaft fragment. This dovetailing, although sufficient while the fragments were surrounded by the capsule and soft parts to prevent crepitus, and to cause the neck and head to rotate in the socket as a whole, did not prevent such attrition of the fragments as would hinder bony union."

Koenig[1] locates fractures of the neck of the femur either near the head or the trochanteric portion, localities which correspond to intra- and extra-capsular fractures. From anatomical reasons, after a fall upon the trochanter major, the anterior wall of the neck (the convex side) fractures first, and the fractured end of the neck is directed forward. In most, if not in all cases, the wedge-shaped end of the inner fragment is implanted into the trochanteric portion, producing impaction.

Adams' arch, the densest and strongest portion of the neck, penetrates the deepest. The greater the inclination of the inner fragment forward, the more extensive the impaction. As a necessary result of this impaction, the head of the femur descends and approaches the posterior inter-trochanteric line; the dislocation of the head in these directions satisfactorily accounts for the shortening and outward rotation of the limb.

Accurate statistics as to the frequency with which impacted fractures occur as compared with non-impacted fractures, are still wanting. The individual experiences of surgeons are so widely at variance on this point, that a final decision can only be rendered after the accumulation of more positive knowledge from accurate bedside observation and post-mortem examinations.

From a study of the literature on this subject it is apparent, however, that the more recent authors advance the opinion that it is

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[1] Lehrbuch der Speciellen Chirurgie, B. II., 1879, S. 837.

of frequent occurrence. It is also evident that impaction is not limited to any particular part of the femoral neck, but that it can follow any fracture, although the most favorable conditions for its occurrence are found at either extremity of the femoral neck. The direction and extent of impaction depend on the density of the tissues which are penetrated, and on the direction and intensity of the fracturing force. Impacted fractures within the capsule may occur from the application of indirect violence, as the capsular ligament will offer the necessary resistance; on the other hand, impacted fractures without the capsular ligament can only take place from direct violence.

It is also possible in cases of this kind, as suggested by several authors, that a simple fracture is produced in the first place by force applied through the axis of the femur, and impaction takes place subsequently by a fall upon the trochanter major. Impaction from indirect violence would necessarily take place at the lower portion of the constricted portion of the neck, by the apex of the femoral brace penetrating the soft spongiosa of the head; while if produced by a fall upon the trochanter major, the compacta of the posterior surface is also implanted into the head. Impaction outside of the capsule, from the normal position of the neck and the direction of the fracturing force, always takes place at the expense of the posterior portion of the neck, except in cases where the fracturing force is so severe as to drive the entire neck wedge-like into the upper portion of the femoral shaft, splitting the latter into two or more fragments.

Impaction implies the destruction or crushing of more or less of bone tissue; and, in case the fragments are unlocked, a vacuum is formed, which must be filled by the interposition of fluids or the adjacent soft tissues. It is well known that intra-capsular fractures are often produced by very slight injuries, and it is equally certain that these are the cases which furnish the most unfavorable prospects for a good result, and the question might naturally arise: Had the violence been sufficient to produce deep penetration, would it not have enhanced the prospects for a more favorable issue? In fractures of the neck of the femur the prospects for a favorable result are better if the exciting cause acts with sufficient intensity to produce impaction, as this condition is the most favorable for repair by bony union.

VIII. Predisposing Causes.

Fracture of the neck of the femur is one of the rarest accidents during childhood and adult life, while after the fiftieth year it constitutes a high percentage of all fractures. Between the ages of twenty-one and thirty it constitutes one-ninety-first of all fractures; between thirty and forty, one-seventy-fourth (Gurlt[1]); between fifty and sixty, nearly one-tenth; and over seventy, one-third. Its frequency increases steadily with the advance of old age. A number of theories have been advanced to explain this clinical fact.

Thus, Richter[2] mentions the following predisposing causes: 1. Spongy texture of neck, and diminution in thickness of compact layer. 2. Diminution in the obliquity of the neck. 3. Prominence of trochanter major, by which the fracturing force is transmitted directly to the neck.

Walther[3] assigns to syphilis an important part. Sex has also been mentioned as a predisposing cause; aged females furnish a greater number of fractures than aged males, and it was claimed that this could be explained by the more horizontal position of the neck in the former than in the latter. As the strength of the femoral neck is derived from the peculiar architectural arrangement of the spongiosa, the simple diminution of its angle would not render it more liable to fracture, as Julius Wolff has shown that, even in fractures that have healed with considerable deformity, the structure of the spongiosa is perfectly restored in accordance with the original plan. If the neck is placed at a right angle to the shaft, it would give way more easily at the constricted portion on the application of indirect violence, while from a mechanical standpoint, it ought to resist force more advantageously in case it is applied in the direction of the axis of the neck.

The predisposing cause is intrinsic, inherent in the bone itself, a degeneration or diminution of bone-tissue. All influences which affect nutrition, and that of bone in particular, as insufficient or improper food, wasting diseases, prolonged confinement in bed, etc., hasten the degeneration of bone, consequent upon senile marasmus. Senile osteo-porosis then is the only known predisposing cause; this assertion is abundantly confirmed by clinical experience.

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[1] Handbuch der Lehre von den Knochenbrueche, 1862, vol. i., p. 30.

[2] Lehrbuch von den Bruechen, etc., 1833.

[3] System der Chirurgie, 1852. B. VI., S. 348.

IX. Exciting Causes.

Fractures of the neck of the femur are produced by:

1. Force applied in a vertical direction through the axis of the femur.

2. Force applied in a horizontal direction over the trochanter major in the axis of the femoral neck.

3. Traction force transmitted through the capsular ligament when the limb is forcibly hyper-extended and adducted and rotated outward.

A fall upon the foot or knee, as a rule, will fracture the neck at its narrowest portion. If the fracture is complete, no impaction will take place, unless it follows as a secondary occurrence from transmission of force through the trochanter major. Most authorities who believe that intra-capsular fractures are the most frequent, assert that indirect violence is the most frequent exciting cause.

Experiments and clinical observation have shown that the majority of fractures of the neck are produced by force applied in the direction of the axis of the neck by falls upon the trochanter major. It is also an established fact that in most instances of this kind the neck gives way at its trochanteric portion, and that the posterior wall is crushed or fractured first. Impaction takes place more frequently from direct force, with deeper penetration of the posterior than the anterior wall of the neck.

Of thirty cases of fracture of the neck examined by Desault[1] for the purpose of learning the exciting cause, twenty-four were produced by a fall upon the trochanter major. All the cases reported by Sabatier appear to have been produced in a similar manner. Sabatier ascribed to the prominence of the greater trochanter an important part in the production of fracture, and believed that fracture of the femoral neck does not occur in children on account of the imperfect development of the upper extremity of the femur.

Although direct force through the axis of the neck generally expends itself near the femoral shaft, causing a fracture of the expanded portion of the neck with posterior impaction, there are a number of cases recorded where the fracture occurred within the

[1] A Treatise on Fractures, etc., 1817.

capsule. Intra-capsular fractures produced in this manner are often impacted.

The last manner in which a fracture of the femoral neck may be produced is by forcible hyper-extension and rotation outward of the limb, movements by which the ilio-femoral ligament is put upon its utmost stretch; and, when this bone has become so fragile that it is unable to resist the traction of this powerful ligament, a fracture, the so-called traction fracture, takes place at the junction of the neck with the femoral shaft. This fracture is always extra-capsular, and was first described by Linhart, and subsequently experimentally studied by Rüdinger.[1] The latter believes the fracture takes place before the patient falls upon the ground; comminution of the trochanter major and impaction may subsequently result from direct violence.

X. Senile Osteo-Porosis.

Senile osteo-porosis is an affection of the bones in the aged, characterized by diminished elasticity and increased fragility as compared with healthy bones. It is an excentric atrophy of bone, due to impairment of the physiological functions which preside over digestion and assimilation. During the incipient stages the bone retains its volume, but loses in density and weight, owing to an actual loss of bone-tissue, which necessarily results in increased porosity. This affection appears first in the spongiosa of the head and neck of the femur, and it is here where its most advanced stages are observed. In the upper end of the femur this senile degeneration weakens the support to vertical pressure, allowing the head gradually to descend in some instances below the summit of the great trochanter, at the same time diminishing the oblique angle of the neck to almost a right angle with the shaft.

Senile, in connection with this subject, however, is a relative term, as this condition of the bones may be found in comparatively young people, provided senile marasmus, the atrophic changes peculiar to old age, from any cause manifests itself; and, on the other hand, even very old people, when otherwise in good health, may remain exempt from this form of senile degeneration. I have in my possession a femur, taken from a gypsy one hundred and four years

[1] Studien über Grund u. Einkeilung d. Schenkelhalsbrueche, 1874. p. 63.

of age at the time of his death, which illustrates this assertion. The neck of the bone retains the normal obliquity, the compact layer is firm and thick, while the spongiosa, although somewhat more porous, presents the different systems of arches in a degree of perfection unsurpassed at any age. Senile atrophy of bone, and the diminution in the obliquity of the neck of the femur resulting from it, have justly received so much attention on the part of pathologists and surgeons, to explain the frequency of fracture, that I may be pardoned for entering more fully into a consideration of this subject.

All authorities agree that the structural degeneration of the neck of the femur is an important, if not the only predisposing cause in the production of fractures in this locality in the aged. The increased brittleness of bones during advanced age has been explained in different ways. Bichat attributed it to an excess of the inorganic constituents of the bone, with a corresponding decrease of the organic matter. This view found almost universal acceptance among surgeons, and is still taught in many of our text-books on surgery.

Henle was among the first to assert that the fragility is not caused by a disproportion of the earthy and organic constituents of bone, but that it is the result of an actual loss of bone tissue, a genuine atrophy of bone. Ribbert[1] has made special inquiries into the pathology of senile atrophy of bone, and from the prevalence of this affection along the lower regions of the Rhine, he has been enabled to study this process under the most favorable circumstances. On examining sections of osteo-porotic bone stained with carmine, he invariably found osteoid red zones upon the surface of the lamella, varying in size, extent, and number in proportion to the severity of the process. These zones presented very delicate parallel lines, and bone-cells with very fine or spindle-shaped projections. The margins of the osteoid layers towards the unchanged portion of the lamella were not very irregular, and were usually devoid of lacunæ. The medulla, as a rule, was pulpy, hyperæmic, and often infiltrated with blood, the medullary spaces dilated, and the lamellæ correspondingly reduced in thickness. In one case he found the latter completely destroyed and converted into osteoid tissue, forming cyst-like cavities filled with pulpy medullary tissue.

[1] Ueber senile Osteo-malacia u. Knochenresorption im Allgemeinen. Archiv. f. Path. Anat., LXXX. S. 436.

Ribbert regards the process as being due to an impairment of nutrition, which of necessity is attended by chemical changes of the basis-substance of the bone, which is followed again by a separation of the earthy phosphates from the basis-substance. The earthy salts are rendered soluble by acids (perhaps carbonic acid) contained in the fluids of the body. As an evidence that the earthy phosphates are separated from the organic tissues, the author mentions that he has seen a granular opacity at the junction of the osteoid spaces with the normal bone, which cleared up on the application of an acid.

Insufficient or improper food has an important influence in impairing the nutrition of bone, as has been abundantly shown by reliable observations. Roloff[1] made experiments on animals for the purpose of studying the pathology of fragility of bones. He was able to produce this condition artificially by depriving the animals of all food containing phosphate of lime. He ascribes the condition primarily to a diminution of the earthy constituents of bone; during the more advanced stages of decalcification a metamorphosis of osteoid into myeloid tissue takes place. The walls of the canaliculi appear more transparent and wider, and present the appearance of light stripes with dark edges. The walls of the bone-cells or spaces become translucent. During the further progress of the metamorphosis the appearances are such as would indicate that the bony tissue over greater or less areas had been entirely destroyed, and its space filled up with new myeloid cells from the adjacent myeloid spaces. A close examination, however, showed that the myeloid cells originated from the bone cells.

Maresch observed an epidemic of fragility of bones among cattle and pigs in Bohemia, which lasted for three years, and was attributable to a prolonged drouth and, consequent upon it, poor quality of food. He invariably found that the disease showed a predilection for the extremities of the long bones, which were softened to such an extent that they could be readily cut with the knife. The interior of the spongiosa was filled with a white pultaceous mass, while the compacta was reduced to a thin shell.

M. Mercier observed that in all specimens of senile atrophy the alveolar spaces were enlarged, rendering the tissue more porous.

[1] Ueber Osteo-malacia u. Rachitis. Virchow's Archiv, B. XXXVII. Hft. 4, S. 434.

Kölliker[1] believes that giant-cells are the agents which produce absorption of bone in normal and pathological conditions. These cells, when found in bone, he calls osteo-klasts. They originate from osteo-blasts, and are found on the surface and in the interior of the lacunæ.

Humphry,[2] in mentioning the causes of fracture of the femoral cervix, alludes to the subject as follows: "In the aged the arrangement of the cancelli which in the young and middle-aged are so admirably adapted to support superimposed weight, becomes imperfect from senile degeneration, a process which begins earliest in the upper end of the femur."

Herman Meyer[3] advanced the idea that senile osteo-porosis appears under the form of a non-suppurating periostitis, the product of which as yet remains unknown.

Gurlt's[4] description of senile osteo-porosis may be condensed as follows: The medullary canal is enlarged, the cortical layer very thin or entirely absent, and the spongiosa exceedingly porous, the meshes being filled with myeloid tissue of a dark color.

Kassowitz[5] affirms that absorption of bone takes place as a consequence of increased vascularization, the loss of bone-tissue being the direct result of absorption.

G. Pommer[6] has studied the process of resorption in diseased bones with a view to determine the formation of Howship's depressions, and the function of the osteo-klasts. His observations, based upon thirty cases of bone atrophy, due either to old age or pressure from any cause, has induced him to accept Kölliker's views as mentioned above.

Morisane has made histological examinations to ascertain the minute processes which take place in the destruction and absorption of bone in cases of rarefying osteitis. He believes that the normal exudation which takes place from the minute vessels in bone in a state of health, is destined to perform the essential part in the pro-

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[1] Die Verbreitung und Bedeutung d. veilkernigen Zellen d. Knochen u. Zaehne. Virchow u. Hirsch Jahresb., vol. i, 1872, p. 21.

[2] Treatise on the Human Skeleton, 1871, p. 471.

[3] Op. cit.

[4] Handbuch von der Lehre der Knochenbruechen, vol. i, 1861.

[5] Virchow u. Hirsch's Jahresbericht, vol. i, 1881, p. 262.

[6] Ueber die lacunaere Resorption im erkrankten Knochen, Weiner Sitzungsbericht. B. 83, Abth. III. S. 17.

duction of bone, but when inflammation is present, chemical changes take place in the exuded material, which annihilate the bone-producing properties of the cells. He distinguishes an acute and chronic form of the disease. In the chronic form the destruction of the compact tissue is the result of a progressive diminution of its earthy phosphates, during which the basis-substance is reduced to fibrillæ, which unite with the connective tissue of the marrow spaces, and undoubtedly materially assist in the formation of the connective tissue framework of these spaces. In the acute form, where nutrition is seriously impaired, the stroma undergoes rapid granular degeneration, while the earthy salts are absorbed, the bone-cells being destroyed instead of being converted into connective tissue, as is the case in the chronic form. In the chronic as well as the acute variety of rarefying osteitis, the death and absorption of bone-tissue is dependent in an intimate manner on the numerical increase and degree of dilatation of the small vessels; and, to a certain extent, it also results from a chemical change which the products of exudation have undergone; to this latter must be assigned an important rôle as a dissolving agent.

I have called attention to inflammatory osteo-porosis of bone under the head of senile osteo-porosis, in order to explain the rapid absorption which takes place after fracture of the neck of the femur. In all of these cases, and more particularly in the intra-capsular variety, more or less of the neck is removed by absorption, in some instances almost the entire neck disappears. This process of absorption after fracture expends itself more on the lower than the upper fragment, and more upon the posterior than the anterior portion of the neck. Interstitial absorption of the neck of the femur in young adults, as described by Gulliver,[1] can only be explained on the hypothesis that inflammatory softening and absorption are induced by traumatism. Only in two cases of the four reported by Gulliver was the diagnosis verified by the autopsy. Both were young men who had suffered contusion of the hip on the affected side: in both the neck was shortened, and almost at a right angle with the shaft; in one of them the cancellated tissue of the neck was more compact, and some adventitious bony material on its surface near the shaft; while in the other case, "the cancelli of the neck were

[1] Interstitial Absorption of Neck of Femur without Fracture. Medico-Chirurgical Review, vol. xvii., p. 543.

filled with caseous matter, in some nearly colorless, in others tinged with dark grumous blood."

Similar specimens have been brought forward as cases of bony union after intra-capsular fracture; there is, however, in all of these cases a symmetrical atrophy of the anterior and posterior portion of the neck of the femur, while in cases of intra-capsular fracture with bony union, there is almost without exception a greater loss of substance of the posterior than of the anterior portion of the neck.

Interstitial absorption of the neck in young adults is always the result of rarefying osteitis, which eventuates in loss of bone-tissue; but after the disease has subsided regeneration takes place, the spongiosa becomes more dense by deposit of new bone, while the same process takes place beneath the periosteum, giving rise to adventitious bone, which might easily be mistaken for callus, as in Case 3 described by Gulliver; in other instances the process of destruction is not followed by repair, the products of inflammation remain in the cancelli, as in Case 4 mentioned by the same author.

There has been considerable difference of opinion in regard to the particular structure which is the primary or most important seat of senile osteo-porosis. Authors have located it in the structures which, in accordance with the views they entertained, were supposed to furnish the principal support to vertical pressure: thus Meyer found it in the spongiosa, Merkel in the calcar femoral, Bigelow in the compact tissue of the neck. Senile degeneration, in preference, affects the spongy bones, and the spongy portions of the long bones; hence, there can be no doubt that it first attacks the spongiosa in the interior of the head and neck of the femur, from which it gradually invades the different parts of the compact tissue.

In order to prove this assertion I have examined a number of sections of the upper extremity of the femur from persons advanced in years, and have repeatedly observed the spongiosa atrophic and porous, while the femoral brace and the calcar femoral retained their normal strength. During the advanced stage of the affection the compacta may be reduced to the thinness of paper, or disappear entirely, the periosteum coming in contact with the spongiosa; in such cases, fracture takes place on the slightest application of force, and the bone can be readily cut with a knife. The myeloid spaces are the starting points of the process of degeneration; they are enlarged and become distended by the accumulation of myeloid cells

and granulation tissue; the cancelli are broken down, and thus spaces of considerable size are created at the expense of the regular system of arches which make up the structure of the spongiosa.

Giant cells and granulation tissue possess the property to disintegrate and absorb bone; they are the destructive agents, while the broken-down tissue is removed by the blood-vessels. When sections of a bone, the seat of senile atrophy, are examined during the earlier stages of the process, they present a vascular and red appearance, on account of increased vascularization and an abundant deposit of red marrow. When degeneration has progressed to the highest degree, the compacta has disappeared almost completely, the spongiosa is exceedingly porous, the alveoli large and filled with fat, and the bone presents a yellow appearance, imparted by the free fat derived from the fatty degeneration of the histological elements.

As long as the bone is supplied with an abundance of myeloid tissue and blood-vessels, its bone-producing capacity is not impaired; on the other hand, it is said to be increased, irrespective of the degree of softening and fragility; but if fatty degeneration has progressed to the extent just mentioned, and the vascular supply is greatly diminished, as is the case in the most aggravated forms of senile osteo-porosis, no attempt at production of bone can reasonably be expected in the event of fracture: We are then justified from a consideration of the foregoing remarks in adopting the following conclusions:

1. Senile osteo-porosis is the only predisposing cause of fractures of the neck of the femur in the aged.

2. Senile osteo-porosis, except in the most advanced stages of fatty infiltration, does not impair, but hastens the production of myeloid, or permanent callus.

XI. Symptoms of Fracture of the Neck of the Femur.

As the very best authorities are forced to admit that during life it is impossible to locate accurately the precise seat of fracture, there exists no longer the necessity of considering the symptoms separately under the head of intra- and extra-capsular fracture. In practice, the greatest care should be exercised to ascertain the presence of impaction; but even impacted fractures present the most important symptoms in common with non-impacted fractures; and they may

be conveniently, and I think profitably grouped together to prevent unnecessary repetition.

The symptoms presented by a fracture through the neck of the femur, as in any other fracture, are: 1. Subjective; 2. Objective.

I. Subjective Symptoms.

The subjective symptoms are: *a*, Pain; *b*, Loss or impairment of function.

a. Pain.

The pain is due either to the immediate effects of the traumatism, laceration of the contiguous soft tissues, irritation produced by the movements of the fractured ends, or the inflammation of the bone or surrounding tissues succeeding the injury. The pain is variable, almost absent and of short duration in some cases, excruciating and continuous for months and sometimes years in others. If the fracture is located in the narrow portion of the neck, the pain is usually referred to the groin about the insertion of the ilio-psoas muscle; if at or near its base, it is more diffuse, and referred to the seat of injury.

There has been considerable discrepancy of opinion as to the severity of the pain in fractures within, as compared with fractures without the capsule. Sir Astley Cooper maintained that it was less severe in the former variety, while Malgaigne claimed that the reverse was true. As fractures of the narrow portion of the neck are the result of less violence than those occurring near the shaft, it is undoubtedly true that the pain attending them immediately after the traumatism is less than in the latter class of injuries, while the reverse may be true during the subsequent history of the case. In impacted fractures, where the favorable conditions for bony union are not disturbed, and the process of repair is initiated at once, and progresses uninterruptedly, the pain, as a symptom, is referable only to the traumatism; and as such, is more severe, as a rule, in fractures where the greatest amount of tissue has been lacerated, that is, in extra-capsular fractures.

In cases of non-impacted fractures within the capsule, with motion of the fragments upon each other, a certain amount of inflammation springs up, which is always attended by its most prominent symptom, pain. When pain, the result of inflammation, is

present, it assumes the characteristic features as witnessed in coxitis independent of fracture. It is then no longer a symptom of fracture, but indicates the accession of traumatic coxitis. The presence of no inconsiderable amount of inflammation has repeatedly been verified at post-mortem examinations, in the form of thickening of the capsule, adhesions, and destruction of the synovial membrane and cartilage. Any attempt at motion or pressure against the trochanter major aggravates the pain. In some old inveterate cases the pain assumes a neuralgic type, which would indicate that some of the nerves about the hip-joint were encroached upon by the displaced fragments, or exuberant callus, or the products of inflammation.

b. Loss or Impairment of Function.

This symptom is present in all fractures of the femoral neck. As a general rule, it may be stated, it is prominent as a symptom in proportion to the degree of separation of the fragments. In impacted fractures the patients are often able not only to move the limb, but even to walk for hours and sometimes days. The impairment of voluntary movements does not depend alone on the direct loss of support, but is also influenced by the pain incident to such movements; hence, this symptom will present itself in the highest degree in nervous, excitable patients. Laceration of the soft parts, the periosteum, and capsule, in the absence of impaction, will also counteract voluntary motion, not only by allowing a greater degree of disjunction of the fragments, but likewise by increasing the pain on any attempt at motion.

In the great majority of cases the patient, as he lies in bed, is unable to raise or move the limb in any direction; it remains perfectly helpless in the position it was left after the accident, or in which it had been left by the displacing elements. In some cases where interlocking of the fragments exists, or where a slight amount of impaction has taken place, the patient has control over a certain amount of voluntary movements for a number of days, or until disjunction of the fragments takes place as a result of injudicious examination or inflammatory osteo-porosis, when the limb is placed in the same conditions as if no impaction had taken place.

2. Objective Symptoms.

The objective symptoms are: *a.* Swelling and deformity at the hip. *b.* Suggillation about the hip. *c.* Eversion of limb. *d.* Shorten-

ing. *e.* Change of position of trochanter major. *f.* Increased or diminished mobility of the hip-joint. *g.* Loss of tension of fascia lata between the trochanter major and the crest of the ilium.

a. Swelling and Deformity.

In all cases there is an appreciable fullness in the fold of the groin corresponding to the seat of fracture. This swelling is caused by the hinge-like projection of the anterior portion of the neck, effusion of blood or inflammatory products, and, lastly, by the over-riding or impaction of the fragments. When impaction takes place at the base of the neck, the trochanteric portion of the femur is enlarged from implantation of the upper fragment. The swelling is larger when the fracture is located without the capsule, from the more extensive bone injury and the more copious effusion of blood.

b. Suggillation.

Suggillation appears earlier and more constantly the nearer the fracture is seated to the femoral shaft. As this symptom is the result of the presence of blood at the point of fracture, it is more extensive if the hæmorrhage has been considerable and outside of the capsule. If the hæmorrhage has been within the capsule, and the capsule is ruptured at some point, the discoloration will usually show itself along the inner side of the thigh. The same force which produced the fracture may also contuse the soft parts sufficiently to give rise to superficial discoloration independent of the fracture.

c. Eversion.

The lower limb in a natural condition is slightly everted on account of the forward obliquity of the femoral neck. This normal eversion is increased during sleep when the muscles are at rest, or when they have been completely relaxed by an anæsthetic, or when their action has been permanently suspended by paralysis. In the normal condition, then, the weight of the limb effects outward rotation until arrested by muscular action, or the resistance offered by the ligament of the hip-joint. As the posterior wall of the neck is usually the seat of more extensive comminution or impaction than the anterior, and as the fracturing force in the majority of cases is applied in the antero-lateral direction, it is only reasonable to expect outward rotation of the limb to be the rule. This expectation has been verified by clinical observation. Until recently it has been

generally supposed that eversion is the result of muscular contraction, and in support of this view it has been suggested that in non-impacted fractures, it increases after the muscles have recovered their contractility.

Edmund Owens, on the ground of anatomical demonstrations and carefully made experiments, as well as accurate clinical observation, holds that eversion of the limb takes place independently of muscular contraction, that it is invariably the result of the impacting force or the weight of the limb, as the case may be. In intra-capsular fractures it is especially true that eversion is more marked a few days after the injury, but this fact can be interpreted more satisfactorily from a different standpoint. In such cases the fragments are often kept in apposition by an interlocking of the broken surfaces or unlacerated portions of the fibrous investment of the neck; either of these supports may give way to the constant traction from the weight of the limb, or the same result may take place from reflex muscular contractions, or careless handling of the limb. After the fracture, the great mass of muscles, the external rotators of the hip, are relaxed from the approximation of their points of origin and insertion, and it is difficult to conceive in what way they could effect outward rotation. Dupuytren believed that eversion may also be due to the action of the adductor muscles, and in some instances to the obliquity of the fracture itself.

It is also necessary to mention that eversion is not a constant symptom. Cases have been described by reliable observers where the limb remained normal so far as the position of the foot was concerned, and in some even the reverse, inversion, occurred. Cases of fracture with inversion have been described by Ambroise Paré, J. L. Petit, Guthrie, Stanley, Dupuytren, Desault, Cruveilhier, Hamilton, R. W. Smith, and others. Desault thought that it occurred in about one case out of every four. Stanley observed one case where the autopsy showed that the fracture was purely intra-capsular, and no satisfactory explanation could be found for the inversion.

Wm. Pirrie mentions a case of intra-capsular fracture where the limb was not only inverted but also strongly flexed and adducted, a position he ascribed to the tension of the ilio-femoral ligament. Of the one hundred and thirty cases of intra-capsular fracture of the neck of the femur which came under Pirrie's observation, and in which the accuracy of the diagnosis was verified by dissection,

this was the only case with flexion, adduction, and rotation inward of the limb. Of the remaining number, inversion existed in only one case, the limb in other respects occupying the usual straight position.

Malgaigne[1] reports an exceedingly interesting case. "In 1833, having found the foot inverted in a fracture of the neck of the femur, I ascertained that it was easily everted and again inverted at will, and that it remained as readily in one position as in the other; *whence I concluded that whatever inclination is given to the part upon the supporting plane it keeps by its own weight.*"[2] This observation is exceedingly valuable, and would lead us to the conclusion that whenever the support derived from the cervical portion of the femur is lost, the limb will follow the natural law of gravitation, and will turn outward by its own weight, unless opposed by some special conditions at the seat of fracture, or by external influences.

d. Shortening.

The significance of shortening as a symptom of fracture of the neck of the femur has received additional interest, since it has been ascertained that frequently there is a natural difference in the length of the lower extremities in the same individual. Dr. J. S. Wight, of Brooklyn, has made a valuable contribution to surgery relating to the comparative length of the inferior extremities in the same individual. His first published table comprised the measurements of sixty persons, of varied nationalities, pursuits and ages. In these sixty there were ten persons who presented a parity of length in the two legs, and fifty who showed a difference varying from one-fourth of an inch to one and three-eighths inches. The right leg was longer in eighteen, and the left in thirty-two instances. A second table comprises forty-two measurements, and shows a parity of length in thirteen, and a difference in twenty-nine instances, the difference varying from one-fourth of an inch to one inch. In nine cases the right, and in twenty the left limb was the longer. Hamilton has corroborated these statements by his own researches.

Gurson[3] has made some further investigations which tend to

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[1] A Treatise on Fractures. Translated by J. H. Packard, M.D., p. 543.

[2] Italics my own.

[3] Inequality in Length of the Lower Limbs. Journ. of Anat. and Phys., vol. xiii, p. 26.

establish the correctness of these observations. He examined seventy skeletons of different sexes and ages, and belonging to different races. He found that the lower extremities were of the same length in only seven of this number, and among these the femur, tibia and fibula were of the same length on both sides in two, while in the remaining five the tibia and fibula and the femur equalized the difference in length. In 54 per cent. of the cases the left extremity was longer than the right, the average difference being 4.8 mm., and the maximum difference 13 mm. The right extremity was longer than the left in 55.8 per cent., with an average difference in length of 3.3 mm., and a maximum of only 8 mm. These measurements not only prove that the lower limbs differ in length in a majority of the cases examined, but they likewise point out the importance of measuring the long bones separately for the sake of comparison, when measurements are made for diagnostic purposes.

More or less shortening will take place in every case of fracture of the neck. M. Lisfranc and M. Lallemand[1] each have reported a case where the limb was lengthened. It is impossible to conceive in what manner the fracture could add to the length of the limb; still the observations were undoubtedly correct, and an explanation can only be given by assuming that the amount of actual shortening was slight, and that the patient's limbs were of unequal length. The amount of shortening depends on the degree of disjunction; the greater the longitudinal displacement, the greater the shortening. The shortening is always the direct result of muscular contraction or longitudinal displacement by impaction. In impacted fractures the maximum is reached at once, and the degree of shortening depends on the depth of penetration or mutual inter-penetration of the fractured ends. In cases of impaction the shortening remains stationary, as the fracture is not disturbed, and can only increase on the advent of inflammatory interstitial absorption.

In fractures without the capsule, all resistance to muscular contraction is lost, and the maximum amount of shortening is reached as soon as the muscles have become contracted. If the capsule is intact, and remains attached to the lower fragment, shortening takes place gradually by stretching of the capsular ligament. In case the fragments are held in contact by the denticulated fractured surface,

[1] Dupuytren, Injuries and Diseases of Bones.

shortening can only proceed after this medium of apposition has been removed by displacement of the bones, or after inflammatory osteo-porosis has removed the projecting spiculæ. This condition is often met with in intra-capsular fractures. The degree of shortening immediately after a fracture has been relied upon by some in determining the seat of fracture. Among surgeons there has been, however, such discrepancy of opinion in this respect, that no reliable deductions can be drawn from this circumstance in rendering a decision.

Sir Astley Cooper and Amesbury claim the greatest shortening for intra-capsular fractures, while Stanley, Earle, and R. W. Smith entertain an opposite opinion. Impaction and the integrity of the capsular ligament are such important factors in determining the amount of shortening and the time when it takes place, that these conditions must be carefully considered in estimating the value of shortening as a diagnostic aid.

e. Change of Position of Trochanter Major.

The trochanter major is displaced upward and backward, in proportion to the amount of shortening and eversion. When shortening has taken place, its upper border has passed beyond Nélaton's line. When the limb is rotated, it describes a smaller arc of a circle. It is less prominent when impaction has taken place, or when the lower fragment is not in apposition with the upper.

f. Alteration of Motion.

A false point of motion is always established in non-impacted fractures. Preternatural mobility is most marked if the fracture is not impacted and if it be located outside of the capsule. It is probably in cases of this kind that Gerdy has been able to rotate the limb outward until the toes looked backward, and that Maisonneuve brought into requisition his test of hyper-extension. If the fracture is within the intact capsule, the latter will serve as a retentive measure, and limit the motion between the fractured bones. Dr. Levis has found that in non-impacted fractures the limb can be extended beyond its normal length. In case firm impaction has taken place, the neck has become shorter and thicker, conditions which necessarily impair the natural mobility of the hip-joint.

g. Fascia Lata.

Dr. Allis,[1] of Philadelphia, has added another symptom, which indicates fracture through the neck of the femur, namely, the existence of a relaxed condition of the fascia lata between the crest of the ilium and the trochanter major on the injured side, produced by the loss of resistance, which is furnished by the neck when not broken. As the presence of this symptom depends on the dislocation of the lower fragment upward and inward, it is only met with when such changes have taken place. The standing position is the only one in which this test can be applied, as in the reclining position the muscles that make tense the fascia are relaxed.

Bezzi[2] has called attention to a sign which he considers as pathognomonic of fracture of the neck of the femur. In examining the space between the trochanter and the crest of the ilium, it will be found that while on the same side the muscles occupying this region (the tensor vaginæ femoris and gluteus medius) are tense, and offer to the hand a considerable feeling of resistance, they present on the affected side a deep, well-marked depression, flaccidity and diminution of tension, from displacement upward of their points of insertion. This sign appears under the same circumstances, and possesses the same significance as the one described by Dr. Allis.

I have intentionally omitted to mention crepitus as a symptom, as more harm than benefit has accrued from the efforts of the anxious surgeon to establish a positive diagnosis on the presence or absence of this sign. A careful study of the other symptoms will usually enable us to arrive at a correct conclusion, without exposing the patient to the risks incident to the manipulations necessary for the purpose of eliciting this symptom.

XII. Diagnosis.

All manipulations, during the examination of a supposed fracture through the cervix femoris, should be performed with the utmost care and gentleness. The so-called "thorough examination," the search for positive symptoms, has been the source of incalculable mischief. In many instances careless handling of the limb has

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[1] Mechanism of the Hip-Joint. Med. & Surg. Reporter, vol. xxxvi., p. 303.

[2] Centralbl. für Chirurgie, July 31, 1880.

resulted in the disjunction of impacted fractures, or in the tearing of periosteal or ligamentous bands, thus precluding most effectually possible union by bone or the formation of a short fibrous union. Years ago, Davis[1] entered his protest against such reckless examinations in the following emphatic manner: "Now, while we willingly concede the importance of a correct diagnosis in its bearings upon the successful treatment of any case, we hold that too much handling and manipulation of the limb in intra-capsular fracture is liable to eventuate in irreparable injury to the patient." Again: "When this connecting link of periosteum and capsular ligament is not severed by officious handling on the part of the surgeon, in his zealous, but often mischievous efforts to ascertain to the fullest extent the details of the injury, then we may hope for better results than have usually followed this accident."

Bryant's[2] caution is equally strong: "In fact the ordinary fracture of the base of the neck of the thigh-bone is primarily an impacted fracture, the impacted bone in some cases being loosened by a second fall, in others by excess of violence received in the original accident, and *in too many by the manipulations of the surgeon in his anxiety to make out the presence of a fracture by the detection of crepitus.* Indeed, this seeking for crepitus in cases of fracture is a practice fraught with danger."

I shall not allude to crepitus as a diagnostic sign, as a satisfactory diagnosis can usually be made without it, by a careful consideration of the other symptoms. In every case of suspected fracture we should make careful search for evidences of senile osteo-porosis, and ascertain as nearly as possible the amount of force applied, and the direction in which it was applied. If the general appearance of the patient indicates the existence of far-advanced senile osteoporosis, the amount of force has been slight; and if inflicted in the direction of the axis of the thigh-bone, it is more than probable that the fracture has occurred within the capsule. If the fracturing force has been greater, and applied transversely in the axis of the femoral neck, we have reason to expect that the fracture has taken place, at least partly, without the capsule.

The sudden and complete loss of function of the limb after an injury to the hip in a person over fifty years of age speaks strongly

[1] Conservative Surgery, 1867, p. 23.

[2] Bryant's Practice of Surgery. Edited by J. B. Roberts. p. 842.

in favor of a fracture through the femoral neck. We can say with Hodgson: "If an elderly person, after a fall upon the hip, is unable to use the injured limb, it is very probable that a fracture of the neck of the femur has been sustained, and this is more likely to be the case, if, during the fall, no such great force has acted upon the greater trochanter as would be necessary to produce a contusion sufficiently severe to render the limb useless."

Aside from a general consideration of the case, the diagnosis will depend on the presence or absence of the two most important symptoms, shortening and eversion. Many of our best surgeons depend almost exclusively on accurate measurements in rendering a diagnosis. The amount of immediate shortening will vary according to the presence or absence of impaction, from a few lines to two inches. In impacted fractures the shortening is immediate, and remains stationary unless displacement takes place, or during the reparative process, the femoral neck is shortened by interstitial absorption. The progressive shortening, a few days after the accident, is due to a loosening of the fragments which have been in mutual contact by denticulated projections, and to a gradual stretching of untorn portions of the capsular ligament. Mr. Bryant, in speaking of the utility of his "test-line," says: "Indeed, as a proof of its use, I may add that twenty-five consecutive cases of fracture of the neck of the thigh-bone, admitted into my wards to the end of 1877 (the average age of the patients being seventy-four), left the hospital with union of the broken bones and useful limbs."

Dr. J. S. Wight, of Brooklyn, has written an exceedingly interesting and practical paper on diagnosis of fractures of the femoral neck, based on the report of twenty-one cases.[1] For the purpose of avoiding errors, which might accrue from asymmetry of the lower extremities, he directs that the following measurements should be taken: "1. Inside measurements from the superior anterior spines of the ilium to the lower ends of the internal malleoli. 2. Outside measurements from the superior anterior spines of the ilium to the lower ends of the external malleoli. 3. Measurements from the tops of the great trochanters to the lower ends of the external malleoli. 4. Measurements from the bases of the

[1] The Diagnosis of Twenty-one Cases of Fracture of the Neck of the Femur. Proceedings of the Med. Soc. of the County of Kings. Oct. 1881.

tibiæ to the lower ends of the internal malleoli. 5. Measurements from the superior anterior spines of the ilium to a line drawn transversely in front between the tops of the great trochanters."

The object of all these comparative measurements is to determine the possibility of original asymmetry of the two limbs, and to find out, as far as possible, if the injury to the hip has caused any shortening of the limb on the injured side, so that we can infer the *probability* of there being a fracture of the femoral neck. He gives the results of examination of twenty-one such fractures, where a diagnosis was made without eliciting crepitus. In eight of these cases there was probably impaction. The average shortening was .58 inch, as shown by the inside and outside measurements. In no case of fracture of the femoral neck does he use force to find crepitus. He considers the other evidences of fracture sufficient for a practical conclusion. His concluding statements contain so many practical and useful suggestions that I do not hesitate to quote them in full.

"1. Moving the outer fragment when it is in contact with the inner fragment, will generally carry the inner fragment with it, and there will be no crepitus. And, when there is impaction, ordinary manipulation will not cause crepitus to be felt. Yet crepitus may, at times, be felt when there is impaction of the neck of the femur. 2. Moving the outer fragment when it is not in contact with the inner fragment, of course will not give crepitus. 3. Hence, unwarrantable force will be required in order to get crepitus in many cases of fracture of the neck of the femur, and more than this—*an impacted fracture of the neck of the femur may be broken up by severe manipulation, and a patient that would have had a useful limb may be quite completely disabled for life—for an impacted fracture of the neck of the femur is the best setting of the bony fragments that a surgeon can have.*

"In a suspected fracture of the neck of the femur, I examine all the witnesses of fracture except crepitus, and if these witnesses agree substantially, I pronounce a verdict in favor of fracture of the neck of the femur; and if there is a doubt as to the correctness of such a verdict, I give the patient the benefit of that doubt by treating the case as if there was a fracture of the neck of the femur, and then the surgeon receives a benefit from the doubt. But if there is

no fracture, the patient has had some days of needful rest, and has had a contused hip well treated."

The instrument recommended is an accurate steel tape-line, with feet and inches on one side, and meters and centimeters on the other side. This tape-line will not elongate under tension. It is superfluous to mention that the patient should be placed in the recumbent position, on an even surface, when the measurements are taken. It is to be hoped that the text-books of the future will say less of crepitus as a sign of fracture, and will substitute for it accurate methods of measurement.

Eversion of the limb is the next most reliable symptom. In impacted fractures the position of the limb depends on the direction of the fracturing force. If the force acts in the direction of the axis of the cervix, and is severe, causing implantation of the whole base of the neck into the trochanteric portion of the femur, the limb will retain its natural position. If the anterior wall is impacted by force applied against the outer and posterior aspect of the trochanter major, the limb will remain in a position of inward rotation. From the anterior obliquity of the neck, and the usual manner of falling (forward and on the side), and from the thinness of the compacta of the posterior concave surface of the neck, as compared with the anterior, we would naturally infer that posterior impaction takes place in the great majority of cases. This supposition has been abundantly verified by clinical observation. Impaction, then, is usually attended by eversion. If the fracture is located within the capsule, eversion will frequently increase for a few days, or weeks, after the accident, from the same causes which give rise to secondary shortening. In cases of posterior impaction, where the fragments remain firmly implanted during the process of repair, eversion increases from the weight of the limb and the inflammatory absorption of the impacted fragments, permitting increased rotation outward of the lower fragment.

The abnormal position of the trochanter major is also an important diagnostic sign. If we can exclude dislocation of the hip upward and backward, the application of Nélaton's test may decide the diagnosis. In cases of fracture of the neck of the femur, the upper border of the greater trochanter will be found above Nélaton's line, the distance corresponding with the amount of shortening. In non-impacted fractures, the false point of motion diminishes the axis

of rotation which the greater trochanter describes in rotating the limb. This symptom is mentioned simply to be condemned, as the manipulations necessary to apply this test, like the search for crepitus, have done a great deal more harm than good.

In doubtful cases, more particularly when dislocation is suspected, the patient should be carefully placed in the erect position; when the position of the limb and an examination of the contour of the hip, as well as an inspection of all the landmarks in that locality, will render material assistance in arriving at correct conclusions. In case of doubt, if we err at all, we should err on the safe side, and treat the case as one of fracture. Many cases which were in a condition most favorable for bony union to take place, have been rendered hopeless by not following this rule. The surgeon should ever bear in mind that the most favorable cases present the least degree of deformity, and that in our anxiety to make a correct diagnosis we may sacrifice all the conditions which are essential for obtaining bony union.

In response to my circular as to the possibility of bony union after impacted intra-capsular fracture, Prof. Alfred C. Post, of New York, after replying in the affirmative, kindly wrote: "But the difficulty in proving this proposition depends on two circumstances: 1. The want of absolute demonstration that fracture has actually occurred. 2. The want of opportunity to demonstrate by autopsy that bony union has actually occurred.

"It is a common thing for a person of advanced age to meet with an accident rendering him or her unable to stand or walk, or to raise the affected limb from the bed. There is a certain amount of pain and lameness about the hip, with eversion of the toes, and a scarcely perceptible shortening of the limb. On careful examination, without using much force, neither crepitus nor abnormal motion can be detected.

"There is probable evidence, but not certain demonstration of impacted intra-capsular fracture. If the surgeon is contented with this imperfect diagnosis, he treats the case as one of fracture, and recovery takes place with a perfectly sound limb. But the proof of the fracture and reunion is incomplete. If the surgeon in his anxiety to obtain a perfect diagnosis moves the limb freely in all directions, he overcomes the impaction, rupturing the cervical ligament, demonstrates beyond all doubt the existence of the fracture,

and effectually destroys all hope of reunion. For my part, I prefer an imperfect diagnosis for the surgeon and a perfect limb for the patient, rather than a perfect diagnosis for the surgeon and a useless limb for the patient."

These remarks require no explanation. They are concise, plain, practical, and to the point. Unimpacted fractures of the neck of the femur seldom give rise to any difficulty in diagnosis; the symptoms attending them are so well marked that a correct conclusion can be reached without causing needless suffering, or sacrificing important tissues in searching for any one particular positive sign. Fractures with impaction present the same symptoms in a minor degree; their presence can usually be recognized by a careful consideration of symptoms, the elucidation of which does not necessitate the disengagement of the fragments. Finally, if we have reason to believe that a fracture with impaction exists, it is our duty to initiate the treatment in accordance with such a supposition, although the symptoms are not sufficiently well marked to warrant the diagnosis.

XIII. Production of Callus.

In assuming an affirmative position concerning the possibility of bony union after intra-capsular fractures, it becomes necessary, from a theoretical standpoint, to allude to the results of recent researches on the production of callus. A brief historical review of this subject will be of interest to illustrate how far the opinions of surgeons, regarding the mode of repair after fractures, have been influenced by the views they entertained as to the source from which callus is produced. Galen looked upon callus as a substance thrown out around the seat of fracture for the purpose of cementing the bones together, without, however, becoming changed into bone. Van Swieten claimed that the cement of Galen is transformed into bone. J. L. Petit compared the healing process of bone with the repair of soft tissues. Duhamel de Monceau attributed to the periosteum and endosteum the function of producing callus. Haller, and his prosector Detlef, believed that the periosteum takes no part in the regeneration of bone, but that callus is derived from the fractured ends of the bones, more especially the myeloid tissue.

Dupuytren, from a clinical aspect, revived the theory of Duhamel, and at the same time attributed to the soft tissues around

the seat of fracture, bone-producing functions. He also introduced the terms provisional and definitive callus. He made the assertion that the definitive callus does not make its appearance until four to five months after the injury, and is not complete before eight to twelve months. Cruveilhier did not recognize the classification of callus described by his teacher, and ascribed its source to the lacerated soft parts surrounding the fractured bone-ends, the periosteum, connective tissue, muscles, tendons, etc.

Bransby B. Cooper defined callus as a plastic exudation from the inflamed ends of the broken bone. Lambron asserted that a broken bone can unite directly through the medium of an interfragmentary callus without the formation of a provisional callus. P. Flourens believed that the periosteum alone is capable of furnishing material for new bone. Subsequently, however, he modified his view, and made a distinction between the periosteal or permanent callus, and the temporary or muscular callus. August Voetsch speaks of callus as the product of traumatic periostitis. Rokitansky declares that callus is developed directly from bone and its connective tissue, including the periosteum.

Reinh. Hein,[1] who has studied this subject with great care by means of the microscope and experimentally, has come to the following conclusions: The regeneration of broken and resected bones commences, as a rule, from connective tissue. The process of regeneration is, at times, limited solely to the connective tissue of bone and periosteum, but in most cases the connective tissue of adjacent parts, more especially the muscles, contribute to it. According to Virchow, callus is produced from connective tissue outside of the bone, as well as from myeloid tissue in the interior of bone.

Preparatory to his studies on the production of callus, Hofmokl[2] has traced the histology of bone during fœtal life. During the development of bone, cartilage cells are transformed into bone-cells. The primary marrow spaces are formed in the interior of cartilage-cells, which, with their contents, are transformed into marrow spaces. The normal development of callus appears, histologically, as a return of perfect bone into its primary stage, embryonal development. The periosteum, bone, and marrow are active in the production of callus.

[1] Ueber die Regen. gebrochener u. resec. Knochen. Virchow's Archiv f. Path. Anat. B. 15, 1858.

[2] Ueber Callusbildung. Virchow u. Hirsch, Jahresbericht, 1874, p. 294.

The neighboring soft tissues assist in the process of repair only in so far that they may become converted into bone. In point of importance, the callus-yielding tissues are arranged in the following order: periosteum, marrow, bone. The bone-cells take an essential part in the production of callus, since they become enlarged, multiply, and thus form marrow spaces with myeloid cells; changes which are observed very distinctly upon the surfaces of the ends of broken bone, on the periosteal, as well as on the medullary side. Ossification invariably begins from the margins of a medullary space.

Gegenbauer[1] takes the ground that bone is produced directly from connective tissue. Sharpey's fibres, if traced carefully, always spring from a bony point between the Haversian canals, from which point they radiate towards both sides into the lamellar systems. The fibres form networks; and, at points of intersection, bone-cells are produced, and a deposit of lamellæ takes place around connective-tissue fibres. The intercellular substance is regarded by Gegenbauer as a product of secretion of cell elements, and not as a metamorphosis of cells, as was asserted by Waldeyer, who believed that the protoplasm of the cells is transformed in part or entire into basis substance.

Kassowitz,[2] in carefully studying the process of ossification, has come to the conclusion, that the deposit of earthy material in the fibrillary reticulum, as well as in the osteo-blasts, is dependent on the condition of the circulation. The fact that the immediate neighborhood of the vessels does not ossify, and that the deposition of earthy material takes place in advance of the vessels, induced him to accept the theory that active circulation prevents the deposition of earthy material, while diminution of blood pressure favors ossification.

Rigal and Vignal's[3] experimental researches on the formation of callus have an important and direct bearing on the process of repair after fractures. Their practical deductions may be summarized as follows: If periosteum is exposed to a moderate degree of irritation, new bone is produced from the marrow beneath the point of irritation directly, without passing through the stage of cartilage. If irritation is increased by displacing the fragments and rubbing

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[1] Ueber die Bildung des Knochengewebes. 2 Mitth. Jenaische Zeitschr. f. Med. B. 3, S. 206.

[2] Die Normale Ossification, etc. Wiener Med. Jahrb., 1879, S. 145.

[3] Virchow u. Hirsch's Jahresbericht, vol. i., 1883, p. 263.

the soft parts, the result is cartilage beneath the periosteum, which is subsequently converted into bone. If the periosteum is completely destroyed by scraping the bone, the defect is repaired by a connective-tissue cicatrix, which somewhat resembles periosteum. If a circular piece of periosteum has been thus removed, and the bone is broken after cicatrization has been completed, perfect union is the result. If the cortical layer of bone is scraped away down to the medullary canal, the defect is replaced by myeloid callus. If the medullary canal is not opened, the process of regeneration is slower, as a considerable period of time will elapse until the resulting rarefying osteitis opens the Haversian canals sufficiently to furnish the required amount of cellular elements from the medullary tissue for the reparative process.

Mr. MacNamara, in alluding to this subject, in his excellent work,[1] as applied to the neck of the femur within the capsule, says: "The ossification of the soft structures which grow from the medullary spaces of the broken bone is, in the human subject, a protracted process, and the tissues concerned are so delicate, that unless they are protected from injury by means of artificial splints, they seldom unite at all."

It is now generally conceded that the provisional or temporary callus is the product of the periosteal and para-periosteal tissues, while the definite or permanent callus is produced directly from the osteoid and myeloid tissues. The provisional callus is nature's splint, its only object being to immobilize the parts until the definitive callus firmly and permanently unites the fragments. The temporary callus is accidental, and appears earliest and most copiously where para-periosteal tissues are most abundant, and motion between the fragments greatest; the intermediate or permanent callus is produced later, and is most certain to take place in spongy bones.

Fractures of the neck of the femur, partly within and partly without the capsule, unite with as much certainty as fractures in other localities in the usual way, by the formation of external and intermediate callus. In this variety of fractures an abundance of callus, sometimes bordering on deformity, designates the exact location of fracture. In intra-capsular fractures, as in fractures within any other joints, the conditions for the formation of external callus

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[1] Diseases of Bones and Joints, 1881.

are unfavorable; hence, we find in all cases purporting to be bony union, imperfect attempts, if any, in this direction. Anatomy, physiology, and experimental research, all tend to prove that in cases of intra-capsular fracture we have all the conditions present which are necessary for the production of intermediate callus, provided the fragments are kept in immediate contact for a sufficient length of time. The neck of the femur has been rendered vascular and porous by senile degeneration, and is supplied with an abundance of bone-producing myeloid tissue.

The vessels in the red marrow, according to recent observation, are also admirably adapted for the purpose of establishing early and free collateral circulation. In 1869, Hoyer made the discovery that the small veins in the red marrow are without walls, their lumen being bounded by the parenchyma of the marrow. Most of the capillaries are also without walls. The small arteries of the marrow consist of a delicate tube of endothelium, and a single layer of muscular fibres. Rindfleisch corroborated these observations. From this peculiar structure of the vessels in the marrow, it is easy to understand how readily the interrupted circulation could be reestablished through immediate contact of the severed vessels, or by canalization through the medium of a blood-clot or mass of exudation material. That intermediate callus is thrown out in cases of intra-capsular fractures, where the fragments have not been kept in apposition, and bony union has failed to take place, is evident from examinations made of specimens where the broken surface of the upper fragment, and sometimes the connecting ligamentous band, presented well-marked spurs of hard compact bone; an appearance alluded to by many observers, but more particularly by Sir Astley Cooper and Mr. MacNamara.

XIV. Can Loose Detached Pieces of Bone Produce Callus, and Aid in Effecting Bony Union?

It has been urged against the possibility of bony union after intra-capsular fractures that the upper fragment is not furnished with a sufficient vascular supply to maintain nutrition, much less to produce callus. Clinical and post-mortem evidence, however, tend to prove that in the great majority of cases the fragment retains its vitality, and that in many instances where bony union has failed to

take place, the fractured surface shows evidence of callus production. In such cases where the fracture was complete, and the fibrous investment of the neck was completely torn across, the requisite vascular supply must have been furnished through the round ligament. If the upper fragment was not nourished from some source it would more frequently disappear by absorption, or suffer necrosis and act as a foreign body, than has been actually observed at the bedside, or in the post-mortem room. The establishment of collateral circulation through the ligamentum teres, in maintaining the vitality of the upper fragment after intra-capsular fractures, is, unquestionably, of more frequent occurrence and of greater importance than many are ready to admit.

Taking it for granted, however, that the ligamentum teres furnishes no vessels to the upper fragment, I shall, nevertheless, endeavor to show that in case of impaction, it can retain its vitality, assist in the formation of callus, and enter into the production of bony union. It has been known for a long time that, in compound fractures, perfectly detached splinters remain innocuous, and assist in the production of bony callus without giving rise to any particular symptoms of irritation, John Hunter[1] expressed himself as follows on this subject: "Adhesion of the detached splinters also takes place, not only in those which are attached to the soft parts, but even such as are entirely loose. (This was shown in a thigh-bone in which one of the splinters had moved quite around on its axis, and adhered by its outer surface to the bone.) I never examined a compound fracture without finding some of those loose pieces, which shows they must be common. Their union must be similar to that in the transplanted teeth."

Ollier and Philip Walther inform us that they have seen the disc of bone separated by the crown of the trephine and entirely removed, reunite with the surrounding bone when replaced.

Prince,[2] in speaking of the drilling operation for ununited fractures, says: "When the operation results in the effusion of plastic lymph without suppuration, there are new centres of ossification in the chips of bone cut off by the drill. These are left in the track of the drill; some of them in the soft callus between the ends

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[1] Works of John Hunter. Edited by James T. Palmer, vol. i., p. 502.

[2] Plastics and Orthopedics, 1871.

of the fragments. That these minute fragments of bone become parts of the living tissue is certain; for, if they did not, they would, by the offensive emanations of dead bone, excite suppuration and work their way to the exterior. The importance of these little fragments cut off by the drill, as centres of ossification, may have received too little attention."

Cases where fragments of bone from the internal table of the skull were completely isolated and yet became attached to the surrounding bone by permanent callus, are reported by Samuel Thomas, Soemmering, Bernhard Beck, Von Bergmann, H. Demme, Cluston, Richet, and Ziegler.

Lossen[1] has studied this subject in connection with comminuted fractures of the long bones, and has come to the conclusion that not all loose fragments necrose, but that many are incorporated in the callus and form part of the living ridge between the fractured ends. He is of the opinion that the vessels of the fragment unite at some point with other vessels in the lacerated district, thus establishing the circulation. In one of his illustrations may be seen a fragment, five centimeters long and one centimeter broad, completely isolated and denuded of its periosteum, which, with its wedge-shaped end, had been driven into the medullary cavity. The upper end was perfectly united with the bony mass filling the medullary cavity, and the lower end could be seen beside the necrotic portion of the fractured bone. It can safely be assumed in this instance, that the vessels in the medullary cavity vascularized the fragment and preserved its vitality. Klebs gives a description of a similar specimen, and believes that the vitality of the medullary tissue and periosteum is sufficient to sustain the physiological activity of isolated fragments of bone under favorable circumstances, production of new bone taking place from the transplanted piece of bone.

Von Bergmann describes a specimen of comminuted fracture of the femur, the result of a gunshot wound during the Turko-Russian War, where a fragment, 7.2 cm. long, 15 mm. broad, and 6 mm. thick, had become completely detached from the soft tissues, and had been forced into the medullary cavity, where it became

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[1] Kriegs-chirurg. Erfahrungen aus den Barackenlazarethen zu Mannheim. Heidelberg u. Karlsruhe, 1870, 1871. Deutsche Zeits. f. Chir. Band II. S. 25.

firmly united with the fractured ends of the bone and the intervening bony callus.

Meek'ren made a series of experiments on animals for the purpose of establishing the fact that isolated fragments of bone devoid of periosteum would, under certain favorable conditions, retain their vitality, and were capable of forming an attachment to bone through the intervention of a bony callus. He removed by the trephine a disc of bone from the skull of a dog, and replaced it. On the twenty-second day he found this disc firmly united by bony callus to the surrounding bone.

Flourens transplanted a piece of rib from a dog, under the periosteum of the tibia of the same animal, and in due time found it united by bony callus. The well-known experiments of Ollier are familiar to every surgeon, but as he placed great importance on the preservation of the periosteum as an essential condition for success in bone transplantation, they are not of great importance for our purpose. The experiments of Kosmowski, to ascertain the exact mode of repair in cases of fracture of the skull, indicate that the reparative process in general, and the union of loose splinters of bone in particular, are accomplished by the osteo-genetic functions of the medullary tissue.

Of great practical importance are the experiments of Jakimowitsch.[1] The experiments were made exclusively on the long bones of dogs, and the vascular connections of the transplanted or replanted piece of bone were demonstrated by means of gelatine injections stained with Berlin blue. To insure success, he places great importance on securing accurate apposition and perfect immobilization of the fragment by stitching the periosteum or soft parts over it, and applying elastic pressure and a fixation splint of plaster-of-paris. The operation was always done under strict antiseptic precautions. To prove that the detached bone had become a part and parcel of the living bone, some of the animals were fed on madder, after the example of J. Wolff. This staining material is deposited during life in the new bone around the fragment in greatest abundance, while it also follows the new vessels into the transplanted piece. In almost all of the cases after death, the

[1] Versuche über d. Wiederanheilen vollkommen getrennter Knochensplitter, Deutsche Zeitschr. f. Chir. B. XV.

vessels of the limb operated upon were injected with gelatine stained with Berlin blue, which afforded an excellent opportunity to follow the course of the vessels into the transplanted or replanted piece of bone. In other instances the examination was made even more complete by decalcifying the bone and submitting it to a microscopical examination.

The results of his experiments induced him to conclude that replantation and transplantation of isolated fragments of bone can be successfully performed if the detached piece retains its former relations to its immediate vicinity. Under such circumstances the piece of bone becomes a living part of the bone through the medium of the intermediate callus, and the re-establishment of vascular connections with the surrounding vessels.

Gurlt[1] describes and furnishes illustrations of two specimens of fracture of the femur, where in each case a large fragment of the cortical layer near the centre of the shaft had become completely detached, and in one instance turned completely around, and yet they were found firmly attached by bony union. Both specimens are from the Museum of the Royal College of Surgeons of England, being numbered 108 and 454. He states further, that in comminuted fractures, where many loose fragments must exist, they furnish no obstacle to ready bony union. The fragments either take part in the formation of callus, or are imbedded in the mass, and are eventually removed by a slow process of absorption.

MacEwen[2] resorted to transplantation of small pieces of bone to restore extensive pathological defects, believing that the blood-clot between the fragments served as a medium through which the vascular connection between the detached bone and surrounding tissues was established. He operated successfully upon a case of necrosis of the humerus, with extensive loss of bone substance, by transplanting into a groove made in the bone, numerous wedge-shaped pieces of bone derived from the tibiæ of six rickety children, the fragments being supplied with periosteum and marrow tissue. The bone grafts retained their vitality, united with, and grew with the bone.

Prof. von Nussbaum has introduced transplantation of bone as a legitimate operation in surgery, for the purpose of supplying bone

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[1] Op. cit.

[2] Virchow u. Hirsch, Jahresbericht, vol. ii., 1881, p. 332.

defect in cases of ununited fracture; and his success, as well as similar operations by several other German surgeons, certainly prove that the vitality of even compact bone is sustained by a minimum amount of blood-supply through a narrow strip of periosteum.

Spongy bone, containing an abundance of marrow tissue and a rich supply of blood-vessels, is endowed with a higher degree of vitality than compact bone; and is, consequently, better adapted to enter into union with surrounding tissues, in case it has become detached.

It has also been established by way of experiment, that in animals, marrow can be transferred to different parts of the body, and that if the operation is successful, the transplanted marrow will produce bone. Baikow, Goujon, and Ollier were successful in their auto-transplantations of marrow, but failed when the tissue was transferred from one animal to another. The most extensive and reliable experiments on marrow transplantation have been made by P. Bruns.[1] He operated upon sixty chickens and six dogs. He failed repeatedly as long as he transplanted the marrow from animal to animal, but as soon as he limited his experiments to auto-transplantation, he succeeded in the great majority of cases. Of nineteen auto-transplantations, twelve proved successful, three failed on account of suppurative inflammation following the operation, and in four the transplanted tissue was absorbed.

The operation consisted in removing cylindrical pieces of marrow from the femur or tibia, 2 to 3 cms. in length, and transplanting them under the skin of the same animal. After the fourteenth day foci of ossification could be distinctly seen, which enlarged and became confluent from the twentieth to the twenty-fourth day. Ossification was preceded by an active proliferation of spindle-shaped cells. The formation of bone takes place from the pre existing osteo-blasts in marrow, an opinion which is also supported by Waldeyer. The yellow and red marrow were used in these experiments, and proved alike capable of producing bone.

The success attending bone and marrow transplantation constitutes a potent argument in favor not only of the *possibility* but the *probability* of bony union after intra-capsular fractures, in the

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[1] Ueber Transplantation von Knochenmark, Archiv. für Klinische Chirurgie. B. XXVI. S. 661.

event that the fractured ends are in accurate and undisturbed apposition for the requisite length of time. The neck of the femur in a state of senile atrophy furnishes a number of favorable conditions for a speedy production of bony callus. It is very vascular, the compact tissue attenuated, the spongiosa exceedingly porous, and its meshes distended with an abundance of bone-producing myeloid tissue.

If perfectly detached and denuded pieces of compact bone, and isolated masses of marrow, can be transferred to a distant part of the body, and when properly transplanted, not only retain their vitality, but become vascular and produce bone, I can see no reason why the upper fragment in intra-capsular fractures, which is still retained in its natural location, should not manifest the same power of self-preservation and repair. In impacted fractures the bone-tissue, marrow, and lacerated vessels are brought in such immediate contact, that the reparative process is taxed only to its minimum extent in restoring the continuity of the bone. In these instances we have an example of bone and marrow transplantation under the most favorable conditions, and the reason it does not succeed oftener, is simply because these favorable conditions, as a rule, do not exist, or are not allowed to exist, for a sufficient length of time.

XV. Specimens of Bony Union after Intra-Capsular Fracture.

It is not my purpose to enter into a discussion of the many specimens in which bony union has been claimed by their possessors. Many of them have been the object of the most rigid criticism, at different times and at the hands of different writers. While careful and competent men have brought these specimens before the profession as typical examples of union by bone within the capsule, equally good observers have failed to see the evidence which justified these claims. I have tabulated only the cases reported by competent observers, and where the diagnosis was verified by a post-mortem examination.

No.	Name of Reporter.	Where Mentioned or Classified.	In Whose Possession.
1	Adams, R.,	Todd's Cyclopedia, vol. ii. p. 813.	Adams.
2	Adler,	Am. Journ. Med. Sci., April, 1873.	Adler.
3	Bardeleben,	Lehrbuch d. Chir. B. ii. p. 477.	Goyrand.
4	Brulatour,	Med.-Chir. Transactions, vol. xiii.	Brulatour.
5	Bryant,	Bryant's Surgery, p. 843.	Museum Guy's Hospital.
6	Callender,	St. Barthol. Hosp. Rep., vol. i. p. 154.	
7	Chassaignac,	These iuaugurale.	Van Houte.
8	Chelius,	Haudb. d. Chir. B. i. p. 319.	Chelius.
9	Chelius,	Haudb. d. Chir. B. i. p. 319.	Soemmering's collection.
10	Cushing,	Bigelow, The Hip, p. 133.	
11	Earle.	Practical Obser. in Surgery, 1823, p. 97.	
12	Fawciugton,	Am. Journ. Med. Sci., vol. xv. p. 534.	Fawcington.
13	Fischer, H.,	Persoual communication.	Pathological Museum, Breslau.
14	Fischer, H.,	Persoual commuuication.	Ponfick.
15	Field,	Amesbury on Fractures.	Field.
16	Geddings,	Am. Journ. Med. Sci., Jan. 1847.	Geddings.
17	Gurlt,	Knochen-brueche, vol. i. p. 308.	Giesseu Museum.
18	Hamilton,	Hamilton on Fractures, p. 407.	Hamilton.
19	Harris,	Am. Journ. Med. Sci,, vol. xviii. p. 246.	Harris.
20	Holthouse,	Holmes' System of Surgery, vol. ii.	St. George's Hosp., Spec. No. 112
21	Howship,	Med.-Chir. Transactions, vol. xiv.	Howship.
22	Hutchinson,	Illustr. Clin. Surgery, vol. ii. p. 8.	Leeds Hospital Museum.
23	Hntchinson,	"Museum Notes" of Jan. 23, 1870.	Museum of Trinity Coll.,Dublin.
24	Jones,	Med.-Chir. Transactions, vol. xxiv.	Jones.
25	Kocher,	Personal communication.	Pathological Museum, Berne.
26	Kroenlein,	Personal communication.	Pathological Museum, Zurich.
27	Langstaff,	Med.-Chir. Transactious, vol. xiii.	Langstaff.
28	Maas.	Personal communication.	Pathological Museum, Freiburg
29	Malgaigne,	A Treatise on Fractures, 1859, p. 555.	Musee Dupuytren.
30	March,	Trans. Am. Med. Association, 1858.	Museum Albany College.
31	March,	Trans. Am. Med. Association, 1858.	Museum Albany College.
32	March,	Trans. Am. Med. Association, 1858.	Museum Albany College.
33	Mussey,	Am. Journ. Med. Sci., 1857, p. 299.	Mussey.
34	Mnssey,	Am. Journ. Med. Sci., 1857, p. 299.	Mussey.
35	Mussey,	Am. Journ. Med. Sci., 1857, p. 299.	Mussey.
36	Pope,	Hamilton on Fractures, p. 407.	
37	Post,	Personal communication.	Destroyed in fire of Uuiv. Med. Col.
38	Riedinger,	Studien uber grund u. einkeilung der Schenkelhalsbrueche, 1874. Pl. xi.	Wuerzburg Museum.
39	Roberts,	Personal communicatiou.	Museum Peunsylvania Hospital.
40	Sands,	New York Med. Record, June 1, 1869.	Sands.
41	South,	Chelius Surgery by South, vol. i. p. 621.	South.
42	South,	Quoted by Hamilton, Ed. 1871, p. 363.	Museum St. Barthol. Hosp.
43	Smith, H. H.,	Princ. and Prac. of Surg., vol. ii. p. 610.	Wister and Horner Museum.
44	Smith, H. H.,	Princ. and Prac. of Surg., vol. ii. p. 610.	Smith.
45	Smith, R. W.,	Dublin Journal Med. Sci., Jan. 1873.	Museum Trinity College.
46	Smith, R. W.,	Dublin Journal Med. Sci., Jau. 1873.	Museum Trinity College.
47	Spalding,	Bost. Med. & Surg. Journ., Mar. 4, 1858,	Spalding.
48	Stanley,	Med.-Chir. Review, vol. xii. p. 170.	Stanley.
49	Swan,	On Diseases of Nerves, p. 304.	Swan.
50	Selden,	Trans. Virginia State Med. Soc., 1877.	Selden.
51	Selden,	Trans. Virginia State Med. Soc., 1877.	Selden.
52	Parker, W.,	Johnson, Intracap. Fract., 1857, p. 28.	W. Parker.
53	Zeiss,	Hamilton, Fract. and Disl., 1880, p. 406.	Zeiss.
54	Zeiss,	Hamilton, Fract. and Disl., 1880, p. 406.	Zeiss.

I will only give a description of a few undoubted specimens, for the purpose of illustrating the alterations which take place in the femoral neck during the process of repair. R. Adams (Table, No. 1): "The round ligament was sound. The head and neck of the bone had lost their normal obliquity, and were directed nearly horizontally inwards; the cervix presented, both anteriorly and posteriorly, evidence of a transverse intra-capsular fracture having occurred; the

globule-shaped head was closely approximated behind and below to the posterior inter-trochanteric line, and to the lesser trochanter, so that the neck seemed altogether lost, except anteriorly, where a very well-marked ridge of bone showed the seat of the displacement and of the union of the fragments. This ridge is evidently the upper extremity of the lower fragment of the cervix. The fracture of the neck posteriorly was found to have been closer to the corona of the head than anteriorly, and the fibro-synovial fold in the former situation remained unbroken. A section has been made of the bone through the head, neck and trochanter; one portion has been subjected to maceration and boiling; and the bony union has been unaffected by these tests. Scarcely any portion of the neck can be said to have been left. The section shows the compact line which denotes the union of the fragments; the head and shaft seem to be mutually impacted into each other, and almost the whole of the cervix has been absorbed; the line of union is serrated, solid and immovable; and the cells of the head and substance of the shaft seem to communicate freely in all places, except where the thin line of compact tissue here and there points out the seat of the welding together of the remaining portions of the head and neck of the femur."

As Mr. R. Adams, in his article, "Abnormal Conditions of the Hip-joint," in Todd's Cyclopædia, took the ground that bony union was impossible, and commented unfavorably on the cases which had been reported as cases of bony consolidation, it is evident that this case must have presented convincing proof in order to change his views on this subject. The value of this specimen is increased by a full clinical history of the case.

Chorley's specimen, described by Jonathan Hutchinson (Table, No. 22): "The bone, which supplied the illustration I now publish, is one of the many treasures of the Pathological Museum of the Leeds Hospital. The drawings were (by permission) made for me by Mr. Tuffen West, some years ago, at the time of the visit of the British Medical Association to Leeds. The specimen is the best example of union of an intra-capsular fracture with which I am acquainted, and, as it appears to be beyond all cavil, I have great pleasure in endeavoring to secure for it a wider recognition. The drawings show so exactly the condition of the bone that it is scarcely necessary to describe them. (Figs. 9, 10, 11.) It will be seen that,

whilst the transverse fracture is wholly within the capsule, and nowhere more than half an inch from the articular head, yet, that on the back of the cervix, some fragments have been detached, which pass much further out. It is worth notice, also, that in the section of the bone, the edge of the lower outer layer is seen to catch in the

Fig. 9. Anterior view of Bony Union after Fracture of Neck of Femur. (Hutchinson.)

cancellous tissue of the articular fragment, thus constituting a degree of impaction which, no doubt, much favored fixation and union. The specimen was obtained by the late Mr. Chorley, formerly Surgeon to Leeds Infirmary, from the body of a gentleman, aged seventy, whom he had attended several years before his death, with the diagnosis of fracture of the neck of the thigh-bone. The treat-

ment had been very careful immobilization and long-continued confinement to bed. The recovery had been such that the patient had been able to walk well with a stick."

The well-known ability of Mr. Hutchinson is a sufficient guarantee for the genuineness of this specimen.

FIG. 10. Posterior View of Bony Union after Fracture of Neck of Femur. (Hutchinson.)

Riedinger's specimen (Table, No. 38): "The neck of the femur is considerably shortened, and the head inclines so far backward, that, superiorly, it comes almost completely in contact with the posterior inter-trochanteric line. From behind, only the cartilaginous surface of the head can be seen; downward, the neck is visible to the extent of 1 cm. Above, the length of the neck is 1.5

cm. On the anterior surface, the well-marked denticulated line of fracture can be seen close to the head. Its length is 3 cm. A longitudinal section of the upper portion of the femur, into an anterior and posterior half, discloses the line of fracture in the loosely cancellated tissue of the spongiosa, and more clearly shows

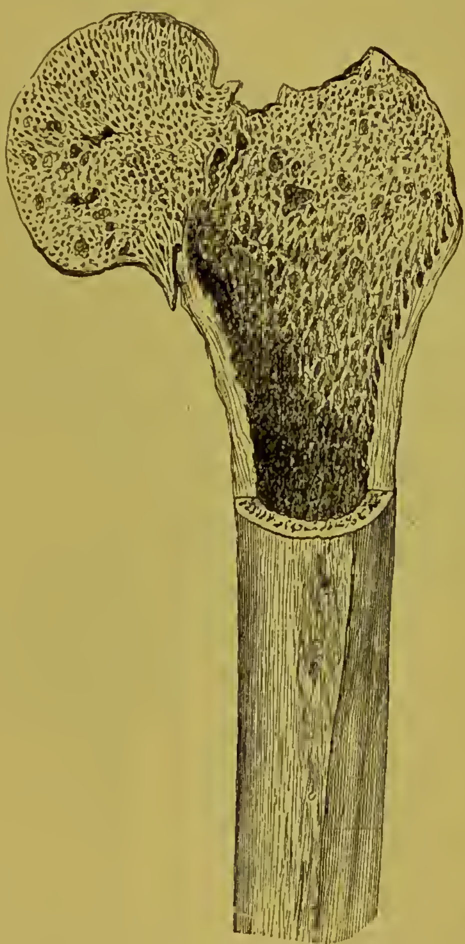

Fig. 11. Vertical section showing Bony Union after Fracture of Neck of Femur. (Hutchinson.)

the impaction of the lower fragment into the head, which is especially well marked in the lower cortical portion of the neck (Adams' arch). The length of the implanted portion amounts to 2 cm." (Figs. 12, 13, 14.)

As Riedinger has made fractures of the neck of the femur a special study for many years, no one would for a moment doubt

the correctness of his description, or the authenticity of this specimen.

Gurlt's specimen (Table, No. 17): "The fracture runs obliquely through the neck of the femur; in front it is three-fourths of an inch from the base of the neck, posteriorly a little less. The head of the bone is displaced somewhat backward and downward and is

FIG. 12. Anterior view of Bony Union after Intra-Capsular Fracture. (Riedinger.)

united by bone, although the line of fracture is still visible in places." (Figs. 15, 16.)

Gurlt's name occupies a position foremost among writers on fractures, present and past, and his decision admits of no appeal.

To prove the validity of any specimen, it is necessary to examine for evidences which will warrant an affirmative answer to the following questions: 1. Has the bone been fractured? 2. Was the

fracture within the capsular ligament? 3. Has the fracture consolidated by bone?

The first question can only arise in specimens without a clinical history. Post-mortem specimens have been brought forward as instances of bony union, when the changes in the bone were due to other causes, as rickets or senile coxitis. In all cases of interstitial absorption without fracture, the wasting of the neck takes place in a

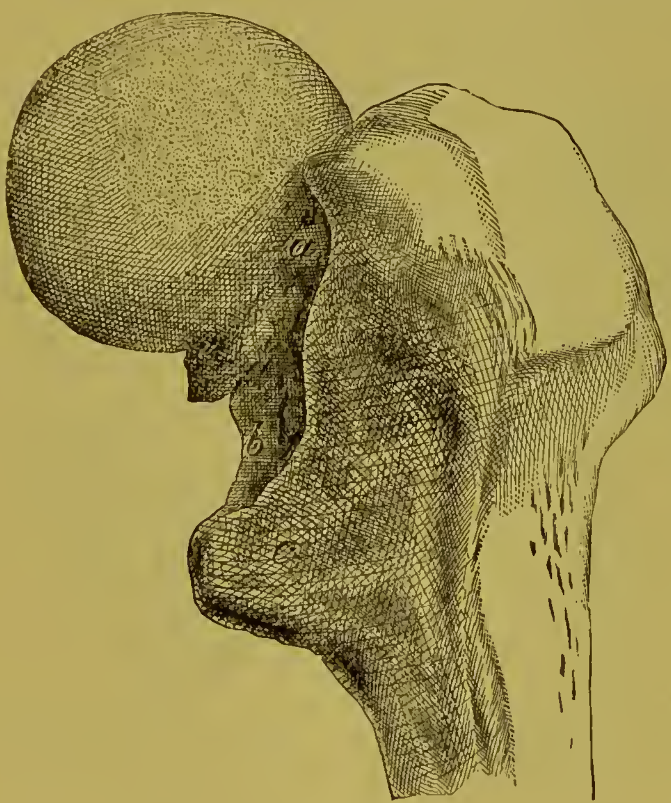

Fig. 13. Posterior view of Bony Union after Intra-Capsular Fracture. (Riedinger.)

more symmetrical manner; the neck may become greatly shortened, and yielding to the vertical pressure, the head may descend to a level with the upper border of the trochanter major, but does not incline backward, as is generally the case when fracture has taken place. In senile coxitis the head is enlarged, and presents the characteristic deep depression for the round ligament; at the same time its upper and anterior surface is deprived of cartilage, and presents an eburnated appearance. (Fig. 17.) If rickets or senile osteo_

malacia has been the cause of the deformity, the disease affects both joints simultaneously. An intra-capsular fracture always unites with some degree of deformity. Longitudinal sections of the specimens usually disclose the direction and extent of displacement of the fragments.

From causes which have been previously enumerated, absorption of the neck is more extensive in the posterior portion of the neck than in the anterior, permitting the head to approach the posterior

FIG. 14. Vertical section showing Impaction with Bony Union after Intra-Capsular Fracture. (Riedinger.)

inter-trochanteric ridge. If the fracture has been entirely within the capsule, little or no provisional callus is found over the seat of fracture, while in senile coxitis irregular bony masses are found over different portions of the neck. The writer on fracture of the neck of the femur in Eulenburg's Encyclopædia says: "If bony union takes place, the femoral neck disappears almost completely by absorption, the head coming nearly in contact with the trochanteric region. Little or no callus is found upon the surface of the neck."

Bardeleben[1] indicates the following appearances as characteristic

[1] Lehrbuch d. Chirurgie, B. II. 1871, S. 473.

of union by bone after fracture within the capsule: "If it can be ascertained with certainty that a fracture had occurred during life, and on post-mortem examination we find a bone cicatrix, that is a disc of dense bone through the intra-capsular portion of the neck, and there are no other evidences of synovitis or osteitis, then we are justified in claiming for such a case that a fracture within the capsule has united by bone."

Erichsen[1] remarks: "When bony union has taken place, the head will usually be found somewhat twisted around, in such a way

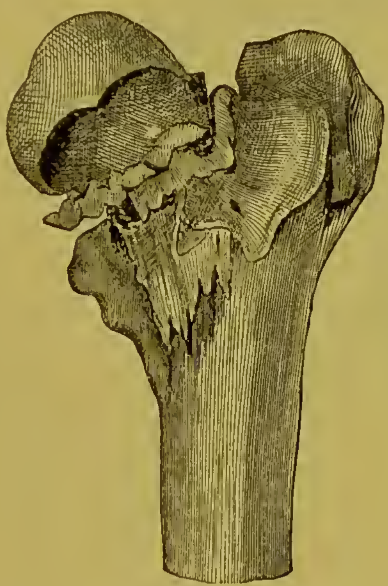

Fig. 15.
Anterior view of Bony Union after Intra-Capsular Fracture. (Gurlt.)

Fig. 16.
Section through Neck showing Bony Union within Capsule. (Gurlt.)

that it looks toward the lesser trochanter, owing to the eversion that has taken place in the lower fragment."

Gurlt[2] states that absorption of the fragments takes place exclusively in fractures involving joints, and proceeds hand in hand with the process of repair. In some joints, as in the hip-joint, it may be so extensive that almost the entire neck is absorbed. This is more likely to be the case if the fracture is within the capsule. In such cases the head of the bone may be very near the great trochan-

[1] The Science and Art of Surgery, 1869.
[2] Handbuch d. Lehre v. d. Knochenbruechen, vol. i., 1862.

ter at the base of the cervix femoris. The cause of the absorption is not known.

The characteristic deformity presented by specimens of bony

Fig. 17. Appearances of Head and Neck of Femur in Senile Coxitis. (Richardson.)

union of fracture through the neck of the femur corresponds to the direction of the displacing forces—shortening and eversion. The cause of the primary displacement is the fracturing force itself. The secondary displacement takes place upon the accession of

inflammatory osteo-porosis, and is the result of softening and absorption of the bone, muscular contraction, and gravitation.

Exacting critics have questioned the validity of many specimens of bony union on the ground that the fracture was not purely intra-capsular. Indeed, this argument has been the main support of all modern believers in non-union. In all specimens of bony union, the point of attachment of the posterior portion of the capsular ligament is changed; instead of being inserted near the middle of the femoral neck, it is found attached at or near the posterior inter-trochanteric line, and on this account it has been asserted that the fracture extended beyond the capsular ligament.

I believe, however, that this alteration in the attachment of the capsule admits of a more satisfactory explanation. All fractures are followed by inflammatory osteo-porosis in the ends of the broken bones, and this is especially well marked in the articular extremities of the long bones. During an inflammation of this kind, the periosteal covering of the bone is loosened, and readily changes its relative position to the bone during the process of interstitial absorption, and carries with it the capsular ligament with which it is intimately connected. Interstitial absorption precedes and attends the production of callus, and is most active in that portion of the bone supplied with the greatest number of blood-vessels. The upper fragment being scantily supplied with blood-vessels, absorption, if it takes place at all, occurs at a later date, and progresses very slowly; while the reverse is the case in the lower fragment. The point of attachment of the capsular ligament is no indication as to the seat of fracture, as almost the entire femoral neck may disappear by absorption, and as the capsule approaches the trochanteric region in proportion to the amount of bone absorbed. A more important sign is the presence or absence of new bone upon the outside of the capsule. In intra-capsular fractures little or no external callus is produced within or without the capsule; while extra-capsular fractures, from obvious anatomical reasons, yield an abundance of exuberant callus, part of which at least, remains permanently.

The last test is to ascertain the nature of the connecting medium. This can be done by submitting the specimen to a microscopical examination, or to the boiling process. In the first case the tissues at the seat of fracture will show the histological elements of true

bone in all genuine specimens. The boiling process will destroy the ligamentous union between the fragments in all doubtful cases; it is, therefore, the simplest and most certain method to demonstrate the restoration of the continuity of the broken bone.

In recapitulation, it may be stated, that the validity of a specimen is established whenever the clinical history has revealed the existence of fracture during life, and the post-mortem examination has demonstrated that the fracture has been within the capsule, and that the union is by bone.

XVI. Non-Union after Intra-Capsular Fracture.

Sir Astley Cooper enumerates the causes of non-union under the following heads: 1. Want of proper apposition of the bones. 2. Want of pressure of one extremity of the broken neck upon the other, even though the limb preserves its length, and the fractured parts are consequently not much displaced. 3. Absence of nutrition in the head of the thigh-bone. 4. Atrophy of bone.

The first cause can apply only to non-impacted fractures, where treatment has failed to keep the fractured ends in immediate and uninterrupted contact for a sufficient length of time for union by bone to take place. This constitutes the principal, if not the only cause of non-union. There is no other fracture where immobilization is so difficult to accomplish. Every movement of the body disturbs the fractured ends. No apparatus yet devised has answered the first and principal indication in the treatment of all fractures, namely, to secure immobility and permanent coaptation.

Colles,[1] who fully endorses the views of Sir Astley Cooper on the subject of fractures within the capsule, in speaking of the causes of non-union, remarks: "However this may be, I think the difficulty of keeping the parts motionless on each other would be sufficient of itself to account for it." Gurlt,[2] who has studied the process of repair in fractures with the most assiduous care, says: "There is no specific tendency to non-union in any form of fracture. If the ends of the broken bones can be kept in accurate apposition, union by bone will take place." As illustrations of this statement, he men-

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[1] Lectures on Surgery, 1845.

[2] Handbuch der Lehre von der Knochenbruechen, vol. i, 1862.

tions the following fractures: Neck of femur, patella, coronoid process of inferior maxilla, coracoid process of scapula, olecranon, coronoid process of ulna, trochanter major, tuberosity of calcaneum, spinous processes of vertebræ, and some of the sharp prominences of the pelvic bones.

The second cause of non-union, want of pressure of one fragment upon the other, implies a want of apposition, expressed in other words. Dupuytren and Brainard were of the opinion that oblique fractures resulted more frequently in non-union than transverse fractures, and Dupuytren applied this rule to fractures of the neck of the femur. Experience has shown that of all fractures within the capsule, none are so prone to result in non-union as transverse fractures through the narrowest portion of the neck. Lateral pressure applied over the trochanter major is an important measure for obtaining union by bone, but this desirable result does not follow from the fact that pressure is made, but simply because, by the pressure, coaptation and immobilization are effected.

Deficient vascular supply of the upper fragment is prominently mentioned by almost every author against the probability of union by bone. On the other hand, it is generally submitted that fractures of the anatomical neck of the humerus unite by bone, and that completely isolated pieces of bone, when properly replanted or transplanted, retain their vitality and physiological properties. It is also well known that traumatic or pathological epiphyseolysis may be repaired by bony callus. Why should the upper fragment in intracapsular fractures, with at least a doubtful supply of blood through the round ligament, make an exception to this general rule? Simply because, in this instance, coaptation, without impaction, is next to impossible, with the present method of treatment.

On this point MacNamara[1] makes this statement: "I hardly think the non-union between the ends of the bone in instances of intra-capsular fracture of the neck of the femur is most frequently due to the insufficient blood-supply of the head of the bone; otherwise we should more commonly meet with examples, after fractures of this kind, in which the head of the bone had become absorbed; but, as you will see in the specimen I now show you, the cancellated tissue of the head of the bone is supplied with blood through vessels

[1] Diseases of Bones and Joints, 1881.

passing along the round ligament and through the fibrous structure uniting it with the trochanter major."

The fractured head of the humerus, deprived of all vascular supply, unites by bone like any other fracture, because the anatomical relations about the seat of fracture are such that coaptation is maintained without difficulty. Fractures within the capsule of the hip-joint will follow the same rule as soon as the surgeon can successfully combat the obstacles which cause displacement. The last cause, atrophy of bone, is the weakest argument in favor of non-union. Clinical experience furnishes abundant proof that in persons suffering from fragilitas ossium fractures not only unite, but unite very promptly. Mr. Holmes, in his System of Surgery, quotes from Gibson the case of a youth of nineteen, who had twenty-four fractures, and from Esquirol another with as many as two hundred fractures. Earle records a case of eight fractures in a child of ten years, and Flemming observed a case where a person suffered fifty-three fractures between the ages of one-and-a-half and twenty-five years. In all of these cases union took place rapidly. Gurlt reports a large number of similar cases. He states very distinctly that *old age does not retard the process of union, as has been erroneously supposed; the reparative process is the same as during adult life.*[1]

I believe non-union is more frequently observed in young, robust persons than in old people. I have seen a fracture of the femur, at the junction of the middle with the upper third, in an old decrepit man suffering at the same time from locomotor ataxia, unite firmly by bone in less than six weeks. Fracture of the lower end of the radius is common after middle life, invariably unites, and in a remarkably short time. Senile osteo-porosis is a condition of bone favorable to the production of intermediate callus. Atrophy of bone facilitates inflammatory osteo-porosis, an event which always precedes the formation of callus. Some authors mention still other causes for non-union, as the presence of synovia and the absence of a nidus for the formative material. Both of these conditions simply remind us that the bones are not in apposition, otherwise they have no significance in preventing union by bone. From this short review we are not only justified, but warranted, in asserting that the only cause for the non-union in cases of intra-capsular fracture is to

[1] Italics my own.

be found in our inability to maintain perfect coaptation and immobilization of the fragments during the time required for bony union to take place.

XVII. Bony Union after Intra-Capsular Fracture.

In a circular letter I addressed to prominent surgeons in this country, England, France, Germany, and Switzerland, for the purpose of ascertaining the prevailing opinion on the subject of bony union after intra-capsular fracture, I asked this question: "In your opinion does bony union ever occur after impacted intra-capsular fracture of the neck of the femur, and under what circumstances?"

To this question I received fifty direct replies. The opinions were divided as follows: Yes, twenty-seven; no, eighteen; doubtful, five. It is a significant fact that the replies from professors of surgery in German universities, five in number, were without exception, in the affirmative, while the greatest diversity of opinion appeared to exist in our own country; at least fifty per cent. of the correspondents replied with an emphatic "No." I believe the answers received reflect correctly the sentiments of the entire profession on this point. If we add the five doubtful correspondents to the eighteen negative, we have nearly fifty per cent. who do not believe it possible for bony union to take place within the capsule even under the most favorable circumstances.

I consulted the text-books and monographs on this subject with about the same result. It would then appear that nearly one-half of the profession still doubt the possibility of union by bone in cases of intra-capsular fracture.

Having shown that there are no anatomical and physiological impossibilities present to prevent osseous union after intra-capsular fracture, and having referred to a number of reliable and well-authenticated cases of this kind, I will quote the opinion of a few recognized authorities on this subject.

Sir Astley Cooper, the originator of the controversy on this subject, and who is always quoted as authority on the negative side of this question, has never denied the possibility of union by bone, as is evident from what he says on page 137 of his work:[1] "I have

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[1] Fractures and Dislocations.

only met with one in which a bony union had taken place, or which did not admit of a motion of one bone upon the other. To deny the possibility of this union (bony union), and to maintain that no exception to the general rule can take place, would be presumptuous, especially when we consider the varieties of direction in which a fracture may occur, and the degree of violence by which it may have been produced." He enumerates a number of conditions which would maintain permanent apposition, and then proceeds: "Such a favorable combination of circumstances is of very rare occurrence." At the time this was written the process of repair in bone was but imperfectly understood, and the occurrence of impaction within the capsule was either unknown, or its importance as an essential element for bony union was not appreciated.

Heister,[1] nearly a century and a half ago, after explaining that the frequency of non-union in cases of fractures of the femoral neck was owing to the difficulty of keeping the broken ends of the bone in apposition, makes the following statement: "If an instrument could be invented which would keep such a limb so extended that during the cure, or at least during the first two or three weeks, it could be kept as long as the healthy one, there would be hope that the fracture could be cured more satisfactorily than has been the case heretofore." Since we have learned that the production of the intermediate callus requires months instead of weeks, Heister would have to modify his statement by greatly extending the period of time required for maintaining apposition.

Desault,[2] in combating the popular idea of insufficient blood supply as a cause of non-union, states: "The head of the bone separated from the soft parts, and attached to the acetabulum by the round ligament, receives a sufficiency of nutriment to enable it to live in that cavity; for there is no instance of its having suffered mortification in consequence of a fracture. Why, then, should it not partake of the properties of life, and particularly of the faculty of reunion when placed in regular apposition with the body of the bone?"

The following quotation is from Syme:[3] "But none of the

[1] Chirurgie, 1747, p. 193.

[2] A Treatise on Fractures, etc. Edited by X. Bichat; translated by Chas. Caldwell, 1817.

[3] The Principles of Surgery, 1832, p. 261.

arguments, which have been adduced to prove the *impossibility* of osseous junction, seems to be conclusive, and though the small extent and mobility of the broken surfaces, the absence of vascular tissues surrounding the fracture, and, perhaps, also the presence of synovial fluid, may render the cure very difficult, it ought still to be regarded as a possible occurrence."

Richter[1] claimed that bony union could take place in impacted fractures, or where, by careful treatment, apposition and retention were fully accomplished. He evidently was impressed with the importance of the bone-producing function of the periosteum, as he advanced the theory, that, in fractures of the neck with complete rupture of the periosteum, under favorable conditions, bridges could be thrown across the line of fracture from one membrane to the other, from which bone could be produced.

Dupuytren,[2] in criticising the treatment followed by the English surgeons, and alluding to the secondary displacements following the too early removal of retaining apparatus, gives the following advice: "But, if these surgeons had adopted the practice of the *Hôtel-Dieu*, in keeping their patients in bed for eighty or even a hundred days, they would have been convinced of the practicability of reunion and complete cure without deformity." And again: "I can only say, for my part, that, if the specimens at the *Hôtel-Dieu* are insufficient to satisfy any one who may take the trouble to examine them, I am at a loss to know what amount of evidence such sceptics would require. For my part, I regard the osseous union of intra-capsular fracture as demonstrated and placed beyond doubt."

Malgaigne[3] is a firm exponent of Sir Astley Cooper's teachings, and yet, after the most critical examination of specimens for which bony union was claimed, he is forced to acknowledge that three of them were genuine. He says: "When a fracture unites, the fragments do not undergo such enormous losses of substance as we should be forced to admit in the neck of the femur; and in Swain's case, which Sir Astley Cooper himself acknowledged as an instance of bony union, the neck of bone had not changed its form. It was

[1] Lehrbuch von den Bruechen und Verrenkungen der Knochen, 1833.

[2] On the Injuries and Diseases of Bones. Edited and translated by F. Le Gros Clark, 1847.

[3] A Treatise on Fractures. Translated from the French by John H. Packard, 1859.

so also in Stanley's case; and, lastly, one femur (No. 188), in the Musée Dupuytren, has lost nothing, either in form or volume, except as the result of very trifling displacement. I admit that these three examples demonstrate quite positively the existence of consolidation; but I cannot say the same of the rest." Loss of substance and change of direction of the neck can no longer be regarded as evidence against the existence of bony union, as they only indicate the presence of impaction followed by interstitial absorption, the consequence of inflammatory osteo-porosis.

Nathan R. Smith,[1] in recommending his anterior splint in the treatment of fractures of the neck of the femur, expresses his convictions as follows: "This apparatus, with slight modifications, is applicable to all fractures of the femur. To none is it more appropriate, and in none has it accomplished more satisfactory results, than in fractures of the cervix, the events of which are so justly regarded as an opprobrium of surgery. So uniformly has non-union and deformity resulted, that eminent surgeons have denied that bony continuity is ever restored within the capsule. We hope to show that these results are rather the consequence of insufficient treatment, than defect in the reparative power of nature."

H. H. Smith[2] advocates the possibility of bony union in the following language: "That osseous union has been seen, cannot reasonably be doubted, and from a careful analysis of the seat of fracture in these cases, I think it is evident that there are a comparatively limited number of cases in which osseous union does occur; and I suggest that, as a general rule, based on observation, it will be found that the nearer a fracture is situated to the head of the bone, or, in other words, the shorter the upper fragment, the greater will be the possibility of osseous union; because the shorter the upper fragment, the greater the chance that the vessels which supply it with blood through the round ligament will be able to furnish it with an amount of material sufficient to enable osseous union to take place by a deposit of bone from the Haversian canals."

Samuel Solly[3] writes: "If you can diagnose that the fracture is an impacted fracture of the cervix, then you may with tolerable

[1] Treatment of Fractures of the Lower Extremity, by the use of the Anterior Suspensory Apparatus, 1867.

[2] The Principles and Practice of Surgery, 1863.

[3] On Fractures of the Neck of the Thigh-Bone. The Lancet, 1867.

confidence predict complete union and a sound limb. I have shown by reference to the preparations in the College of Surgeons' Museum, and also in our own, that fractures of the cervix within the capsule will unite, though not so frequently as those without."

Chelius[1] claims that bony union may have been observed less frequently in England than on the Continent, on account of neglected treatment in cases diagnosticated as intra-capsular fractures.

Erichsen,[2] in discussing this subject, remarks: "In some cases, however, bony union takes place. This may happen when the cervical ligament remains intact, or when the fracture is impacted."

Holthouse[3] says: "Bony union in this fracture (intra-capsular) is rare, and by some has been considered impossible; but a sufficient number of undoubted cases have now been brought to light, both in Europe and America, to place the fact beyond a doubt."

Agnew,[4] in speaking of Astley Cooper's method of treatment of intra-capsular fractures, remarks: " There have been recorded a sufficient number of cases of bony union, after what was believed to be intra-capsular fracture, to justify a hope that some of the cases encountered by the surgeon may have a similar termination."

Gant[5] expresses a similar opinion: "Bony union at one time, and for many years, thought never to take place, does assuredly in some rare cases; but only, it would seem, when the capsular ligament remains entire, or the fragments are impacted, whereby a due supply of blood can be speedily established."

Bryant[6] makes use of the following language: "In the impacted fractures union ought to be looked for if the broken fragments are left alone, and not loosened by a careless and too curious manipulation. In the purely intra-capsular fractures, union may take place, osseous in many cases, fibrous in more."

MacNamara[7] affirms: "I believe, if you can keep the parts at rest, in many cases of intra-capsular fractures, union of the ends of the bones will occur."

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[1] Handbuch der Chirurgie, B. I. S. 119.
[2] The Science and Art of Surgery, 1869.
[3] Holmes' System of Surgery, 1875, vol. ii. p. 846.
[4] Principles and Practice of Surgery, 1878, vol. i. p. 938.
[5] The Science and Art of Surgery, 1878, p. 646.
[6] Principles of Surgery, edited by J. B. Roberts, 1881.
[7] Diseases of Bones and Joints, 1881.

Koenig[1] realizes the importance of impaction in the reparative process, as may be seen from his statement that intra-capsular fractures heal less frequently by osseous union than extra-capsular fractures, because they are less frequently impacted.

Hueter,[2] who classifies fractures of the neck of the femur into those with and without impaction, regardless of the attachment of the capsular ligament, lays it down as a rule that impacted fractures usually unite by bony union.

Stimson,[3] in discussing this subject, advances the following as one of his arguments in favor of the possibility of bony union: "Even if we disregard all existing specimens of alleged bony union, the possibility of such union must, I think, be admitted, because of the demonstrated fact that the head preserves its vitality, and has shown its ability to produce granulations and bone; the former proved by the examples of fibrous union, the latter by eburnation or condensation of its spongy tissue."

I will close the list of witnesses who testify to the possibility of bony union after intra-capsular fracture, by quoting the last sentences of Jonathan Hutchinson's description of the specimen in the Pathological Museum of Leeds Hospital: "This specimen is alluded to by Malgaigne and Hamilton, as if it were of doubtful validity; but neither of them had probably seen it. I cannot but hope that the publication of these life-size drawings of the bone will set at rest all skepticism as to the possible union of intra-capsular fractures. I trust, also, that it may lead to greater hopefulness in the treatment of these accidents, and thus to more systematic care in securing coaptation."

With such an array of unprejudiced, honest, and conscientious witnesses before us, who unanimously and most positively testify that union by bone can, and not unfrequently does take place, we are no longer warranted in denying its possibility. The number of well-authenticated specimens has been gradually increasing, and the knowledge derived from clinical observation and experimental investigations on this subject during the last few years, can leave no further doubt as to the production of bony callus in intra-capsular

[1] Lehrbuch der Speciellen Chirurgie, B. II. 1879, S. 857.

[2] Grundriss der Chirurgie, B. II. 1882, S. 884.

[3] A Treatise on Fractures, 1883, p. 503.

fractures. In the interest of science, and for the benefit of the patients, this controversy ought to be and must be decided in favor of the affirmative, and then the profession will be prepared to seek for measures which will secure better results.

XVIII. Treatment.

In no other fracture are the indications for successful treatment so difficult to meet as in fracture of the neck of the femur. Every unprejudiced surgeon is forced to admit, that the usual bad result in these cases is owing more to the insufficiency of the treatment employed than to the anatomico-pathological conditions of the broken bone. The causes of non-union are not to be found in the broken bone, but in the difficulties encountered in the treatment. All the various methods of treatment suggested and practiced have failed in securing perfect coaptation and uninterrupted immobilization. In all intra-capsular fractures union is effected by the production of an intermediate callus, from the broken surfaces; nature's splint, the external callus, for well-known anatomical reasons, is always wanting, hence the surgeon's splint has a more important and prolonged application than in fractures in other localities. The time required for bony union to take place in fractures of the femoral neck is an unusually long one. Gurlt[1] fixes the time at from fifty-six to two hundred and seven days, and the average duration at eighty-four days.

Dupuytren estimates the time at from one hundred to one hundred and twenty days, and states that it has been customary at the *Hôtel-Dieu* to keep these patients in bed at the hospital for eighty to one hundred days. There can be no doubt that many cases, which promised well from the beginning, have terminated unfavorably by abandoning the treatment too early. To prevent secondary displacements, the retentive measures should not be removed for at least eighty to one hundred days. In deciding upon a course of treatment to be pursued it is important to make a distinction between impacted and non-impacted fractures.

In impacted fractures the fragments have been placed in the best possible condition for bony union to take place, and the object of treatment consists simply in maintaining the mutual penetration

[1] Knochenbrueche, vol. 1., p. 331.

until the reparative process is completed, and the continuity of the bone restored. The surgeon must be satisfied with securing consolidation of the broken bone in the position in which it has been placed by the accident. Any attempt to correct the deformity is unjustifiable, and would necessarily result in loosening of the impaction, an event which would almost to a certainty be followed by non-union. Permanent fixation of an impacted fracture is necessary for the following reasons:

1. It maintains the impaction. 2. It prevents secondary shortening and eversion during the stage of inflammatory osteoporosis. 3. By keeping the injured parts at rest, it serves as a preventive measure against the accession of arthritis and para-arthritis. 4. It enables the patient to leave the bed before complete consolidation of the fracture has taken place.

Extension is always contra-indicated in these cases, as it certainly can do no good, and may result in irreparable damage by loosening the impaction. The best dressing to accomplish permanent fixation is a plaster-of-paris bandage. To insure complete immobility of the hip-joint, the bandage must include the injured limb from the toes upwards, the entire pelvis, and the sound limb from the pelvis to at least as far as the knee. For the purpose of greater durability and security of the dressing, a tin or wood splint can be incorporated in the plaster bandage. In the application of this bandage it is necessary to protect all prominent bony projections, more especially the trochanter major over the affected side, with salicylated cotton, to guard against excoriations; a flannel bandage should be applied next to the skin. During the application of the bandages, and until the plaster sets, it is necessary to place the patient on a pelvic rest, as described by Bardeleben. During the setting of the plaster, it is important to make lateral pressure over both the greater trochanters, in order to secure firm support to the broken bone.

With such a dressing, the patient can be moved without fear of disturbing the fracture, and in a few days he can leave the bed, and in a few weeks can walk on crutches, if deemed necessary for the purpose of preventing complications. Unless indications arise, it is advisable not to disturb the dressing until osseous union has become sufficiently firm to support the fragments. It is particularly dangerous to change the dressing from the third to the fifth week, as during

this time the inflammatory osteo-porosis has a tendency to loosen the fragments. I am satisfied that a dressing of this kind is vastly superior to any splint in affording comfort to the patient and securing the best attainable result.

In the treatment of non-impacted fractures the same principles should govern us as in the impacted variety. In this class of fracture, however, another important indication arises, namely, to effect coaptation of the fractured ends; at the same time retention is more difficult to accomplish. The nearer we can imitate impaction, the better the prospects for a favorable result. If we could keep the broken surfaces in perfect coaptation, and maintain retention and immobility, these fractures would heal in the same way as impacted fractures. That these indications have not been fulfilled by the usual treatment with various splints, extension by weight and pulley, and pelvic belt, nobody can deny. Even extra-capsular fractures have healed, as a rule, with so much shortening as to cripple the patients for life, while the results after intra-capsular fractures have almost universally been so bad, that many of the most distinguished surgeons have abandoned all active measures, limiting their treatment exclusively to palliation.

Prominent among the advocates of the expectant treatment in intra-capsular fractures, I will mention Sir Astley Cooper, Velpeau, Langlet, and Lavacherie. That the views of many surgeons on this point have undergone no material change since Sir Astley Cooper's time is apparent from more than one recent work on surgery. I quote verbally from Gant's Surgery, page 647: "No bony union taking place, as a rule, in intra-capsular fractures of the neck of the femur, it will generally be useless to adjust the fracture and apply any retentive apparatus with a view to such union; and the more so, in proportion to the years of the patient."

If the results attending the different methods of treatment have been so bad as to induce men of the highest professional attainments to abandon all active treatment as useless, the question naturally arises: Are there any other means which are better adapted to accomplish the desired result? The question as to possible bony union after intra-capsular fracture, in the light of recent researches, has been decided in the affirmative, and a more practical question arises: How can it be obtained? By what means can we keep the

fragments in mutual coaptation during the process of repair? I would suggest the following points in the treatment: 1. Immediate reduction and coaptation of the fracture under the influence of an anæsthetic. 2. Fixation with a plaster-of-paris splint. 3. Lateral pressure. 4. Direct fixation of fragments by bone-pegs.

1. Immediate Reduction and Coaptation.

Extension by means of the weight and pulley overcomes the shortening only gradually, and seldom completely, at the same time it necessitates the recumbent position for a long time, and thus exposes the patient to all the risks and inconveniences incident to such position. If the patient is placed thoroughly under the influence of an anæsthetic, muscular action is temporarily annihilated, and the limb can be extended at once to its natural length, while coaptation can be effected at the same time.

The advantages arising from immediate reduction and coaptation are the following: 1. The untorn portions of the joint structures are replaced at once into their normal relations; a procedure which cannot fail to influence favorably the circulation in vessels which may have escaped injury. 2. The sharp and irregular margins of the broken surfaces act as irritants to the surrounding soft tissues; immediate reduction, by placing the bones at once in mutual coaptation, acts as a preventive against the supervention of undue inflammation in and around the hip-joint. 3. With coaptation the process of repair is initiated at once, the blood and exudation material between the fragments act as a temporary cement substance, and at the same time serve a useful purpose in re-establishing the interrupted circulation. 4. Perfect reduction and coaptation prevent muscular spasms and diminish pain.

2. Fixation.

Having reduced the fracture, retention should be maintained in a similar manner as in impacted fractures; with the exception, however, that eversion should be carefully corrected. The plaster-of-paris splint is applied as for impacted fracture, only that over the trochanter major of the injured side a fenestrum, about two inches wide and four inches long, is left open for the purpose of applying lateral pressure.

3. Lateral Pressure.

Many fractures of the femoral neck are kept from becoming displaced for a variable period of time by interlocking of the denticulated broken surfaces, a condition which has been called by Bigelow "rabbeting." Believing that the surgeon should imitate the reparative resources of nature wherever it is possible to do so, it appears to me that artificial rabbeting could often be produced by lateral pressure. The fractured surfaces being placed as accurately as possible opposite each other, lateral pressure would cause perfect coaptation and a mutual interlocking of the fragments. Lateral pressure, applied with this view, would be one of the most reliable means to prevent secondary lateral and longitudinal displacements. Pressure, to be effective, must be applied in the direction of the broken neck, that is, over the trochanter major, and in such a manner as not to interfere with the superficial circulation. Pressure with belts and strips of adhesive plaster encircling the whole pelvis, can exert but little influence on the fractured bone, at the same time it impedes the superficial circulation.

With the fenestrated plaster-of-paris splint, pressure can be applied directly over the trochanter major, by placing a well-cushioned pad, with a stiff, unyielding back, corresponding in size to the fenestrum, in the opening of the splint, and applying the necessary amount of pressure by means of a Petit's tourniquet, or some other similar contrivance. A small amount of pressure, if well directed, would be sufficient to retain the fragments in apposition. By removing the pad from time to time, and washing the parts with dilute alcohol, there would be no danger of producing excoriation. The pad could also be made smaller, and the pressure surface changed as often as necessary, as an additional precaution against superficial excoriations.

Lateral pressure and fixation, however, could be applied more directly and advantageously by means of a long, sharp, steel pin, regulated by a set-screw passing through the centre of a curved steel bar, incorporated in the plaster-of-paris bandage over the fenestrum, in such a way that the sharp point of the pin would perforate the soft parts over the centre of the bone of the femoral neck, and by penetrating a small distance into the bone, would secure perfect immobility of both fragments. By removing the steel pin

and adjusting the pad, this instrument can be used for applying ordinary lateral pressure. (Figs. 18, 19.)

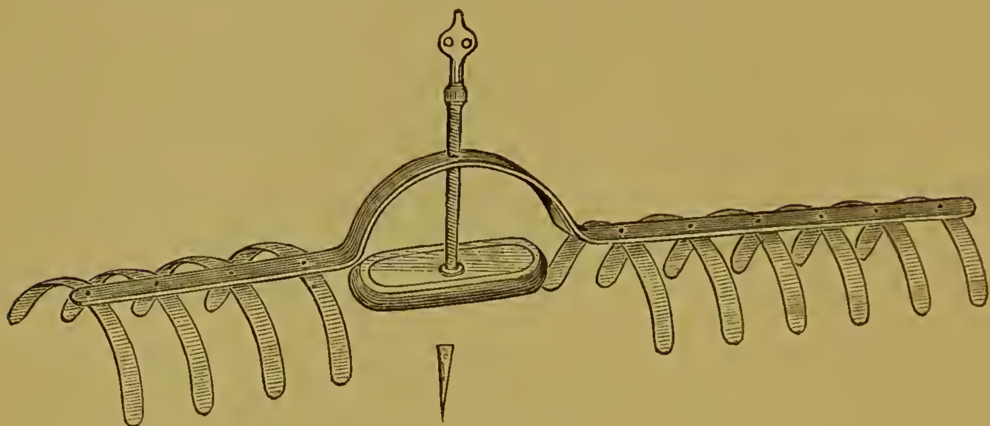

Fig. 18. Apparatus for Treating Fracture of Neck of Femur.

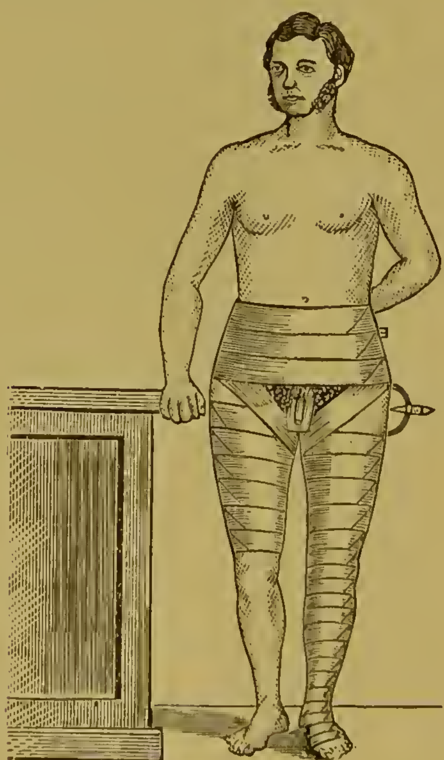

Fig. 19. Apparatus Applied; Steel Point of Instrument Fixed in Trochanter Major.

Heine[1] has used a somewhat similar instrument in the treatment of ununited fractures of the femur and tibia. The superficial site of the greater trochanter would render this dressing of easy application, and from the absence of very sensitive structures, the pain inflicted would not be as severe as in using Malgaigne's hooks for fracture of the patella. Undue inflammation of the soft parts could readily be avoided by the use of antiseptic precautions. It would probably not be necessary to continue this treatment for more than two to four weeks, when the ordinary pad for lateral pressure could be substituted for the steel pin.

4. Direct Fixation by Bone-Pegs.

Apposition of the fractured ends could be secured and maintained with the greatest degree of accuracy by measures which are calculated to operate directly upon the fragments. Such measures have been successful on other joint fractures, where the usual prescribed methods of treatment had failed in effecting union by bone. In the case of fracture of the femoral neck, however, the injured parts are so inaccessible as to exclude the propriety of any cutting operation for the purpose of exposing the fragments to view and securing apposition through the wound. At the same time, this injury is limited almost exclusively to a class of patients whose general condition would forbid an operation of such magnitude for such a purpose. If, however, an operation could be devised which would be devoid of immediate or remote danger to life, that would not incur any loss of blood, nor add to the suffering of the patient, and at the same time would render substantial aid in maintaining permanent apposition of the fragments, then our prospects for securing better results would indeed become more encouraging. I believe we have such an operation in subcutaneous drilling of the neck of the femur, and nailing the fragments together by means of a bone-peg.

The observations of Volkmann and Heine have shown that driving ivory-pegs into osteo-porotic bones will produce an osteoplastic inflammation and osteo-sclerosis. The operations of drilling and insertion of bone-pegs have been resorted to for a long time, for

[1] Ueber operative Behandlung der Pseud-arthrosen, Verh. d. Deutsch. Gesellsch. für Chirurgie, 1877, p. 220.

the purpose of promoting the formation of callus in cases of ununited fractures, and it is only reasonable to assume that the same operations would have a similar effect in recent fractures. The operation offers no great technical difficulties in its execution, and if done under strict antiseptic precautions, does not expose the patient to any additional risks.

The idea of immobilizing fractures by nailing the ends of the broken bone together is not a new one. It is alluded to by David Prince,[1] in treating of the subject of ununited fractures, when he says: "Perhaps a bone might be drilled through both fragments, and held in apposition by a rivet of one of these metals. The presence of the rivet after the completion of the healing process would do no harm, and if a permanent discharge should be the result, the metal could be readily removed."

As yet a discrepancy of opinion prevails as to the future fate of bone- and ivory-pegs when imbedded in living bone. Trendelenburg[2] operated for a very oblique ununited fracture of the femur at the junction of the lower with the middle third, by fixing the fragments with an ivory-peg, He had an opportunity to examine the specimen two and a half years after the operation. The fracture was firmly united, and the ivory-peg was found intact in the bone tissue, having undergone no change whatever, except that a portion which had projected into the knee-joint had become detached, and was found imbedded in a cyst in the interior of the joint, surrounded by giant cells.

Riedinger[3] made a similar observation. Introducing ivory- or bone-pegs into the bones of animals, he found them after a variable period of time either entirely unchanged, or only slightly diminished in size. The diminution in size appeared to be in proportion to the vascularity of the living bone. The growth of the bones thus treated was stimulated, as was shown from an increase in their length as compared with the opposite bones.

Bidder[4] found that by boring a hole in the spongiosa of the epiphysis of the long bones in old rabbits, into the lower end of the

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[1] Plastics and Orthopedics, 1871, p. 220.

[2] Ibid.

[3] Virchow u. Hirsch's Jahresbericht, 1881, vol. ii. p. 333.

[4] Exper. Beiträge u. Anat. Untersuchungen d. Knochengewebe, etc., Archiv f. Klin. Chir. B. XXII. p. 155.

femur for example, that no regeneration of bone took place, the loss of substance being replaced by fibrous and myeloid tissue. In young adult rabbits a slight attempt at regeneration was manifested. The process of regeneration, however, was increased by driving ivory-pegs into the perforations, or by injecting iodine or lactic acid.

Brainard[1] taught that simple perforation of bone increased the formation of callus, while insertion of ivory, wooden, or metallic pegs not only diminished it, but with few exceptions produced absorption of bone.

Volkmann[2] treated a pseud-arthrosis of the femur by excision of the fractured ends, and immobilized the fracture by driving a peg made of a piece of fresh bone, taken from another patient, into the medullary cavity of both ends. The fracture united and the transplanted piece was not seen again.

Riedinger's[3] experiments on animals have shown that ivory- and bone-pegs implanted into bone increase the nutrition of the bone, and remain without giving rise to any undue irritation, and are finally partially or completely absorbed. Metallic substances remain firmly imbedded. Wood and rubber invariably gave rise to suppurative inflammation. Clinical experience and experimental investigations have sufficiently demonstrated that bone- and ivory-pegs, if implanted under antiseptic precautions, do not act as foreign bodies, and never give rise to suppuration; and can, therefore, be safely employed in securing accurate coaptation of recent fractures, if this is deemed desirable and necessary, and not attainable by simpler measures. It has also been shown that these pegs produce osteo-plastic inflammation, and thus materially hasten the process of repair.

The operation of direct immobilization of the fragments by means of bone- or ivory-pegs is, therefore, particularly adapted to the treatment of intra-capsular fractures, whenever it is decided to make every legitimate attempt to secure union by bone. A somewhat similar operation has been performed several times for the purpose of relieving the pain incident to pseud-arthrosis, following fractures of the femoral neck. Before the introduction of antiseptic

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[1] Treatment of Ununited Fractures, Trans. Am. Med. Assoc. 1858.

[2] Ueber Pseud-arthrosen der Vorderarm Knochen. Verh. d. Deutsch. Gesell. f. Chir., ii. 1881, p. 167.

[3] Verhandl. d. Deutschen Gesellsch. f. Chir., 1877, p. 134.

surgery, Von Langenbeck[1] operated by exposing the greater trochanter, and passing a silvered drill through it into the upper fragment so as to secure apposition. The fracture was oblique and intra-capsular in an aged female. The operation was followed by destructive inflammation, hospital gangrene, and death. Lister operated in a similar manner, but under the protection of antiseptic surgery; and secured a good result by a short fibrous union.[2] In this case, however, it appears that the upper fragment was not transfixed by the screw. Koenig[3] repeated Langenbeck's operation under antiseptic precautions, and secured a favorable result.

My experiments on animals have satisfied me that it is not always an easy task to find the upper fragment with the drill, and perforate it at the proper point. To overcome this difficulty, it has been suggested by Trendelenburg,[4] to expose the seat of fracture by a small incision from behind, and after forcibly abducting the limb, perforate the lower fragment from within outward; then, by reinserting the drill from without inward, guided by a finger in the wound, after straightening the limb, to transfix the upper fragment. A silver screw is inserted in the hole made by the drill, and the two fragments are screwed together. The screw is to be removed after two weeks. For the purposes for which we have urged the operation, Trendelenburg's advice is too severe and dangerous. By using bone- or ivory-pegs no disastrous results would follow in the event the peg should miss the upper fragment and be driven into the joint.

Trendelenburg's case and my experiments on animals furnish positive proof that bone- and ivory-pegs driven into the interior of joints do not give rise to any serious results. The operation of drilling the femoral neck and the subsequent insertion of the ivory-peg is facilitated by placing the limb in its natural position and securing it by the plaster-of-paris dressing. The drilling is done through the fenestrum over the greater trochanter in the plaster splint, by sliding the skin and making a passage for the drill through the soft tissues down to the bone with a tenotome, at a point corresponding to the centre of the base of the femoral neck, and drilling in the

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[1] Verhandlungen d. Deutschen Gesellsch. f. Chirurgie, 1878, p. 92.

[2] MacCormac, Antiseptic Surgery, 1880, p. 200.

[3] Verhandlungen d. Deutschen Gesellsch. f. Chirurgie, 1878, p. 93.

[4] Idem.

direction of its axis toward and into the femoral head. The length of the bone- or ivory-peg should correspond to the distance between the outer surface of the greater trochanter and the centre of the femoral head. The advantages arising from the treatment as suggested above would be:

1. The most perfect degree of coaptation and immobilization of the fragments.

2. The patient could be placed in any position in bed, or even be taken out-doors as soon as the dressing is applied, thus effectually preventing excoriations and the diseases incident to prolonged confinement to bed in the recumbent position.

I do not advise, of course, that all the means suggested should be called into use in every case. When the general condition of the patient is such as to preclude any possibility of obtaining a good result, the severer measures, which aim at accurate adjustment and immobilization, are not to be used. In such cases, it is only necessary to adjust the parts as accurately as possible, and apply the plaster-of-paris dressing, which, by keeping the parts at rest, secures for the patient the greatest degree of comfort, and, moreover, does not exclude the possibility of recovery by the formation of a short ligamentous union. If the patient's health is fair, and the symptoms are such as point to the existence of the fracture within the capsule, then we are justified in resorting to the means which will insure the greatest accuracy in the approximation of the parts, and thus furnish nature with the only known means by which she can restore the continuity of the bone.

EXPERIMENTAL RESEARCHES ON CICATRIZATION IN BLOOD-VESSELS AFTER LIGATURE.[1]

Skillful treatment of hæmorrhage is an infallible criterion of good surgery. Dieffenbach has well said, "From the behavior of a surgeon in cases of severe hæmorrhage are we able to judge of what metal he is made." The mechanical measures employed in the management of hæmorrhage have at all times constituted subjects of special interest to surgeons. Presence of mind, a steady hand, prompt action, an accurate anatomical knowledge, familiarity with the various hæmostatic agents, and clear ideas on the process of cicatrization in vessels, are prerequisite conditions of success in the treatment of the most frequent, and, at the same time, the most alarming emergency which presents itself to the surgeon—hæmorrhage.

Ignorance, hesitation, and timidity, in the event of sudden, unexpected, and alarming hæmorrhage, only too often mean death; while, on the other hand, the exercise of skill founded on knowledge is often the means of saving human life under the most desperate circumstances. For the benefit of suffering humanity, fear of hæmorrhage has deterred pretenders from performing bloody operations, which has left the cultivation of the field of operative surgery to men of skill and science.

Perhaps no branch of surgery has reached a higher degree of perfection than the treatment of injuries and diseases of the blood-vessels. The bold operations which have characterized the present era of surgery owe their inception and their legitimacy to the aseptic ligature. The aseptic ligature and the antiseptic treatment of wounds have rendered secondary hæmorrhage an exceedingly rare accident after operations. Every surgeon of the late war of the Rebellion is painfully aware of the frequency with which secondary hæmorrhage occurred after gunshot injuries or any of the capital operations.

[1] Read before the American Surgical Association, 1884.

Billroth reported twenty-three cases of ligation of large arteries after gunshot wounds, and of this number in seven, or 30.4 per cent., secondary hæmorrhage took place. Porta collected six hundred cases of ligation of large arteries, including the aorta, innominata, carotid, subclavian, axillary, common iliac, external iliac, and femoral; of this number seventy-five, or 12.5 per cent., were followed by secondary hæmorrhage. Pilz has published a table of ligation of the common carotid artery where the operation was done one hundred and fifty-eight times for hæmorrhage; of these cases thirty-five, or 33.5 per cent., suffered from secondary hæmorrhage, which proved fatal in sixteen, or 15 per cent.

How different the results of to-day! An artery is ligated, the ligature is cut short, the wound heals by primary union, and permanent obliteration of the vessel is the rule. The aseptic ligature, wherever and whenever it can be applied, has almost entirely displaced all other hæmostatic agents, and is now universally acknowledged as the safest and most reliable measure in securing provisional and definitive closure of vessels. Like all material improvements, it has met with opposition, but a more extended trial has silenced criticism. Every surgeon should be in possession of clear and definite ideas of the processes which nature employs in effecting cicatrization in blood-vessels after ligature, so as to qualify him to select and apply the various hæmostatic agents intelligently, and to measure their effect by well-defined anatomico-pathological principles.

This subject has for a long time furnished a fertile field for theoretical speculations, pathological investigations, and experimental research.

For more than forty years the doctrine has been prevalent that definitive closure of a vessel after ligature is invariably due to the formation and organization of a thrombus. This doctrine is still taught by many of our teachers and recent text-books on surgery. The object of this paper is to disprove this assertion, and to establish the fact that the production of the intravascular cicatrix is always the result of proliferation of the stable connective-tissue cells and endothelia of the walls of the vessel, independently of the formation of a thrombus. The various theories which have been advanced to explain the process of obliteration in vessels will be briefly mentioned in their proper order, and the results of different methods of experi-

mentation will be described, and, finally, the results of my own experimental work will be noticed.

I. History of the Ligature.[1]

For a better elucidation of our subject it is necessary to briefly pass in review the history of the ligature, as it will reflect in a true light the pathological ideas entertained by surgeons at different times regarding its immediate and remote effects in arresting the circulation in a vessel after ligation.

The history of the ligature has been variable and eventful, and has always been intimately connected with the history of surgery, ever constituting a reliable barometer indicating the status, the rise and fall, in the art and science of surgery. Its use as a hæmostatic agent was not the result of reasoning or logical deduction, but was prompted by instinct. It was used and described long before the circulation of the blood was discovered. The discovery of the circulation, anatomico-pathological investigations, experimental researches, and clinical observations have all contributed in rescuing this invaluable agent from the dark domain of empiricism, and have secured for it a position as a remedial agent second to none in points of importance, reliability, and frequency of use.

The first account of the application of a ligature for the purpose of preventing hæmorrhage is given by Sus'rutas, a disciple of the divine Dhavantari, in his Ayur Vedas (1500 B. C.), who tied the umbilical cord in newly-born infants, with a string, eight inches from the navel, previous to cutting it. A number of writers, among them Platner, Holtze, Langenbeck and Fischer, allude to Hippocrates (460-377 B. C.) as the discoverer of the ligature. They base their opinion on the following passage from his works, translated into Latin by Fassius:[2] "Sanguinem e renis profluentem sistunt animi deliquium, figura aliorsum tendens, venæ interceptio, linamentum contortum, appositio, deligatio."

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[1] In the preparation of this part of the paper I am greatly indebted to the following articles: W. Greifenberger, Historisch-kritische Darstellung der Lehre von den Unterbindung der Blutgefässe. Deutsche Zeit. f. Chir., vol. xvi. A. Adamkiewiez, Die mechanischen Blutstillungsmittel bei verletzen Arterien, von Paré bis auf die reneste Zeit. Archiv für Klin. Chir., vol. xiv.

[2] Hippocratis medicorum omnium facile principis opera omnia quæ exstant. Frankf. ii. p. 1194.

Archigenes (100 B. C.) made free use of the ligature after amputations. Celsus (30–25 B. C., 45–50 A. D.), in his works, refers to the ligature as a well-known remedy, and credits an obscure physician of the Alexandrian school with its discovery. Celsus used the ordinary linen thread, and gave particular indications for its use and manner of application. In speaking of the operation for hydrocele, he says:[1] "Nervus, ex quo testiculus dependet, præcidendus; post id venæ et arteriæ ad inguen *lino deligandæ* et infra vinculum abscindendæ sunt."

Galen (131-211 A. D.), who although no practical surgeon himself, was yet familiar with the literature of that day, frequently mentions the ligature, and gives particular directions to apply it to the proximal end of the bleeding vessel. For ligature material he advises silk and fine catgut. The definite closure of the vessel he attributes to the action of the tissues surrounding it, as is evident from the following quotation:[2] "Quæ namque caso in abscisis vasorum partibus coalescit, ea pro opercula est ac osculum eorum claudit." The name of Antyllus (350, A. D.) occupies such a prominent position in surgery of the blood-vessels, and his method of procedure in cases of aneurism is so familiar to every student in surgery, that more than a simple allusion to his name would appear superfluous.

Paulus Ægineta (625-690, A. D.) treats extensively of the ligature, quoting freely from the writings of Celsus and Galen. In practicing ligation of vessels as a therapeutical measure in diverse affections, he passed two ligatures beneath the vessel with the aid of a needle, cut the vessel between them, and, after permitting the requisite amount of blood to escape, closed each end of the vessel separately. Rhazes (850-922, A. D.) mentions, as a last resort to arrest hæmorrhage from large vessels, the ligature which he made of strong linen thread.

The prolific writer, Avicenna (980-1037, A. D.), disposes of the subject of ligation of vessels briefly thus:[3] "Quod si (sc. vena) fuerit

[1] Aul. Corn. Celsi de medicina libri octo, quos ad Leon. Targæ recens, de J. H. Waldeck, Münster, 1827, p. 150.

[2] Claudii Galeni opera omnia. C. G. Kühn, Lipsiæ, 1827, T. x. L. iii. cap. xxii. p. 941.

[3] Avicennæ Arabum medicorum principis Canon medicinæ, ex Gerardi Cremonensis versione per Fabium Paulinum Utinensem. Venetiis apud Juntas. 1595, Lib. iv. Tract. ii. cap. 17.

pulsatilis, tum melius est ut veles eam cum filio lini, et similiter si fuerit non pulsatilis, verum tamen multoties elevatur sanguis ejus." Aneurisms he treats in accordance with the teachings of Antyllus. He limits ligation to arteries, believing that bleeding from veins is arrested spontaneously or yields to the use of the customary styptics.

Avenzoar (1113-1162 or 1196, A. D.) and Averroes (1198) were familiar with the ligature. The latter, in his commentaries on the writings of Avicenna, directs that in performing arteriotomy the vessel should be surrounded by two ligatures before it is divided.

Roland (1252), a pupil of Roger, of Parma (1214), again mentions the use of the needle in applying the ligature, a practice followed by most of the prominent Italian surgeons at that time.

Bruno, of Castel Longobrugo (1252), pointed out the difference between arterial and venous hæmorrhage, and gave the advice, in case the bleeding could not be arrested by any other means, to seize the artery or vein with a small hook and carry a thread with a needle around the vessel and tie it firmly.

Guy de Chauliac (1300-1363) prefers the ligature when the artery is deeply seated, in which case it is well brought into view, and that end is firmly tied which is placed towards the heart or liver.

Lenardo Bertapaglia (died 1460) modified the intermediate ligation by passing the needle armed with a double thread not *under*, but *through* the artery, tying both ligatures firmly over each other. Giovanni Vigo (1460-1520), the founder of the school of surgery in Rome, was acquainted with the direct or immediate ligature, but gave preference to the intermediate method of ligation.

Alfonzo Ferri described the ligature needle used at that time in applying the intermediate ligature, which was about three inches in length and curved only at the point, with the eye at the opposite end; the point presented four sides with obtuse angles, so as to prevent injury to the vessel or its adjacent parts. This needle was armed with a double ligature, entered about two-thirds of a fingers'-breadth from the margin of the wound, was passed underneath the vessel, and made to emerge on the opposite side of the wound, and the ligature firmly tied in several knots.

Angelo Bolognini (1508), founder of the school at Bologna,

also practiced percutaneous ligation of vessels, using silk as a ligature material.

Jacques Houllier (1493-1562) in wounds of the arteries relied on digital compression, and, when this failed and the vessel was deeply located, he advised that it be gently drawn forward, slightly twisted, and, after ligating both ends, divided completely at the point of injury.

In Germany we find the first mention of the ligature by Hans von Pfoloprundt. Hieronymus Brunschwig (1450-1533) practiced and described Bertapaglia's method of ligation.

Hans von Gersdorf (1517), a military surgeon of great experience, frequently applied the intermediate ligature in cases of vessel wounds, but preferred styptics and the actual cautery in amputations.

Walter Ryff tied the proximal end of the vessel by isolating and seizing it with a small hook, and tying firmly with a silk ligature.

It will be seen that, up to this time, the ligature had for the most part only been used as a *dernier ressort* in cases of wounds of vessels, while styptics and the actual cautery were still relied upon as the safest and easiest methods of arresting hæmorrhage.

To Ambrose Paré (1517-1590) surgery owes a great debt of gratitude, not as the discoverer, but as the first and most devoted champion of the ligature. Through his influence and untiring zeal the ligature gradually found its way into popular favor, and displaced the barbarous treatment by styptics and cautery. He practiced both the immediate and intermediate ligation, according to the location of the vessel and circumstances of the case. His first operations were performed about the year 1552. In a German translation of his work on Surgery,[1] published in the year 1601, I find the following directions:

"Wo auch dieses nicht helffen wolte, so muss man die Haeffte, wofern deren eins oder mehr vorgangen, widerumb aufthun, und under der verletzten ader, gegen ihrem Anfang oder Wurtzel zu, mit einer Nadel und Faden durchhin fuhren, die Ader sampt einer solchen portion oder stücklein Fleisches desselbigen Orts, wie viel nemlich die Gelegenheit geben und erleiden mag, fassen und zubinden. Denn also hab ich offtmahlen sehr grosse und gewaltige

[1] Wundt Artzney, od. Artzney spiegell. Translated from the Latin by Petr. Offenbach, Frankf. 1601, p. 372.

Verblutungen, auch in denen Wunden, durch welche gantze Arm oder Schenkel abgehawen worden, gestillt, wie an seinem ort sol gemeldet werden. Dieses aber zu verrichten, werden wir vielmal genötiget, die ganze Haut, so über der Ader light, auffzuschneiden und zu entblössen. Denn wenn eine auss den Blut oder Lufftadern des Halses (Jugularium) durchschnitten were, und sich die beyde Ende, beydes hinauff und hinabwertz von einander gezogen, und also verborgen hetten, muss man die gantze Haut unter welche sie sich verschlossen, eröffnen, die Ader entdecken, mit einer Nadel und Faden darunter hinfahren, und also zusammenbinden, wie ich dan selbst vielmahl sehr glücklichen und wohl verrichtet. Du solt aber dieses Bandt oder Faden nicht eher auflösen, biss dass du sihest, das die Ader mit Fleisch überwachsen, und der Ader Mundlöchlein verstopfet sey, damit das Blut nicht widerumb und von neuwen zu rinnen anfange."

For fear of secondary hæmorrhage Paré favored the ribbon ligature, made of a number of threads; at the same time he aimed to include portions of tissue surrounding the vessel, and removed the ligature as soon as healthy granulations covered the exposed portion of the vessel. He used the ligature with a view simply to approximate the inner walls of the vessel for a sufficient length of time for union to take place, when its further presence was considered useless and even detrimental.

The contemporaries of Paré were slow to acknowledge the superiority of the ligature over the rude, but time-honored cautery. On the one hand, ignorance and prejudice combined in checking progress; while, on the other, it must be acknowledged that Paré's ligature was an exceedingly imperfect thing, which, when used according to his directions, could not fail to frequently disappoint the most ardent admirer. It required centuries to establish it in the confidence of the profession.

Jacques Guillemeau (1550–1613), Paré's pupil, friend, and successor, labored faithfully and earnestly in the interest of the cause of his illustrious master. He was one of the first to resume the operation on arteries in their continuity for the cure of aneurism. He applied the ligature on the cardiac side, opened the sac, and allowed it to heal by granulation.

Pierre Dionis (died 1718) states that at his time the cautery was used almost exclusively at the *Hôtel Dieu* after amputations,

although he resorted to the ligature frequently, and in some instances even practiced immediate ligation. In 1733, Petit (1654–1750) writes of the ligature:[1] "La ligature cause des grandes douleurs, des tressaillements convulsifs et quelque fois la convulsion du Moignon, qui souvent est mortelle ou par ellemême ou parce-qu'elle occasionne l'hémorrhagie par les mouvements extraordinairs que la malade ne peut s'empêcher de faire."

Fabricius von Hilden (1560–1634) and Scultetus (1595–1645) introduced Paré's practice into Germany. The former made use of the hemp ligature, but restricted its application to young healthy persons.

Cornelius von Solingen (died 1692) practiced immediate ligation after the example of Dionis. Anton Nuck (died 1692) only made use of the ligament in operating for aneurism after the method of Antyllus.

In England the ligature was introduced by Wiseman (1566–1625) and was eagerly adopted after the discovery of the circulation by Harvey in 1619.

Fabricius ab Aquapendente (died 1620) applied two ligatures to arteries and divided the vessel between them, so as to allow both ends to retract.

Marcus Aurelianus Severinus (1580–1656) was the first to tie the femoral artery near Poupart's ligament.

Cesare Magati (1597–1647) followed the advice of Galen and Avicenna, and tied the vessels only on the cardiac side.

Kirkland (1721–1798) attributes the definitive closure of vessels after ligation to the inherent contractibility of the vessel wall.

White and Aikin expressed a similar view, as becomes apparent from the following passage: "That the arteries, by their natural contraction, coalesce as far as their first ramification."[2]

John Bell (1760 – 1820) concurred in this view, but added another important element, adhesive inflammation in the vessel wall induced by the ligature.[3]

Larrey (1766–1842) observed that in many cases after ligation no coagulum formed, and, in consequence, asserted that definitive

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[1] Mém de l'Acad. Royale des Sciences, 1733, p. 91.

[2] Cases in Surgery, p. 171.

[3] Discourses on the Nature and Cure of Wounds, 1800, p. 109.

obliteration of the vessel can take place independently of it, and is then due to contraction of the vessel wall.

Richerand (1779–1840) believed that the ligature brings the inner walls of the vessel in contact, and that direct adhesion takes place, the result of adhesive inflammation.

Garengeot (1688–1759) feared the cutting through of the ligature, and, for the purpose of preventing this accident, advised the use of a broad, ribbon-like ligature.

Claude Ponteau (1725–1775) abandoned the use of the broad ligature, but, to guard against the same evil, included within the ligature a sufficient amount of paravascular tissue.

Lorenz Heister (1683–1758) used a stout ligature, and tied over a small cylinder of lint to prevent premature cutting through of the ligature.

J. Z. Platner (1694–1747) made use of a similar contrivance, but always applied a double ligature, with a third (reserve ligature) on the cardiac side, to be tied in the event of secondary hæmorrhage.

Alexander Monroe (1697–1767) protested against the intermediate ligature, and emphasized the importance of direct ligation. He used broad ligatures, and tied only with sufficient firmness to approximate the inner walls of the vessel.

Wm. Bromfield (1712–1792) isolated the artery, drawing it out on the surface of the wound with a hook of his own construction, which still bears his name, and applied a flat ligature.

In France, Deschamps (1740–1824) advocated the superiority of immediate ligation by means of a broad ligature, on the ground that when the intermediate ligature is used, the interposed tissues disappear very rapidly, leaving the ligature loose around the artery, thus favoring the occurrence of secondary hæmorrhage.

Abernethy (1763–1831) applied a double ligature in tying an artery in its continuity, and divided the vessel between them, claiming that in so doing he was able to relieve the tension in the peripheral portion of the vessel, and, at the same time, to enable both ends of the artery to retract into the tissues. He also condemned the reserve ligature, as it would necessitate more extensive isolation of the vessel, thus cutting off nutrition, and provoking a higher degree of inflammation and suppuration.

August Gottleib Richter (1742–1812) introduced the immediate ligature into Germany.

On Dec. 12, 1785, John Hunter (1728–1793), for the first time, tied the femoral artery *in loco prædilectionis* for popliteal aneurism. He applied four ligatures at short interspaces, of which number only the most distal one was tied firmly; the remaining ligatures were tied in such a manner that the lumen of the proximal end of the artery represented a cone, with the base towards the cardiac side of the vessel. Hunter anticipated that this method of operation would favor the formation of thrombus, and thus afford additional security against secondary hæmorrhage. His expectations, however, were not realized, as secondary hæmorrhage occurred on three different occasions, and the patient did not recover until seven months had elapsed. He did not repeat this operation, and subsequently used only one ligature.

Desault accidentally made the observation that in the ordinary method of ligation with the round ligature the two inner tunics of the artery are ruptured.

This fact was verified by Jones, who, in 1806, made a series of careful experiments to determine this point. The classical work of Jones exerted a potent influence in establishing the claims of the ligature, not only in England but wherever surgery was practiced. He claimed that obliteration of an artery after ligature can take place, independently of the formation of a thrombus, by the traumatic inflammation and plastic exudation induced by the ligature. In his experiments on animals he applied several ligatures in close proximity. He called particular attention to the deleterious effects of suppuration on the process of cicatrization in the blood-vessels, and, for the purpose of guarding against this event, advised the removal of the ligatures immediately after they had ruptured the internal coats or before suppuration was established. He believed that provisional closure of the vessel is accomplished by the lacerated tissues within the lumen of the vessel, and that the healing process within the vessel is the same as in any other wound, producing the definite obliteration. In tying large arteries he advised the double ligature and division of the vessel between.

B. Travers adopted the views promulgated by Jones, but substituted the temporary for the momentary ligature. He recommended the removal of the ligature as soon as plastic inflammation was fully established, and before suppuration had had time to take place. The period of time in which the ligature would accomplish this

object he placed at forty-eight to ninety hours, according to the size of the vessel which had been ligated. Jones and Travers deserve to be called the discoverers of the temporary ligature upon a scientific basis. On Feb. 14th, 1817, Travers, for the first time, put his theory into actual practice. He ligated the brachial artery for aneurism, and removed the ligature after fifty hours. The case proved successful. The next case, the artery being the same, did not terminate so favorably; secondary hæmorrhage set in and proved fatal. J. Hutchinson's case, operated on in a similar manner, also terminated in death by recurring hæmorrhages.

Sir Astley Cooper applied the temporary ligature in two instances; the results not meeting his expectations he abandoned it. Among the most formidable opponents of the temporary ligature may be mentioned Hodgson, Vacca Berlinghieri, and C. J. M. Langenbeck, who claimed that it was impossible to determine the exact length of time after which it would be safe to remove the ligature, and that the necessary manipulations for the removal of the ligature would interfere with the prompt healing of the wound.

In Italy, Antonio Scarpa (1747–1832) strongly advocated the employment of the temporary ligature. He used the broad ligature tied over a cylinder of lint for the purpose of bringing and keeping in apposition a large surface of the inner walls of the vessel. His experiments have demonstrated that obliteration of a vessel by adhesive inflammation can and does take place without division of the inner coats. He compared the inner surface of blood-vessels with serous membranes, and credited it with the property of undergoing the same pathological changes when subjected to traumatism. He ascertained that adhesive inflammation followed about four days after the application of the ligature, while the time required for suppuration to arise required from one to two days longer, consequently he determined the time for the removal of the ligature in accordance with the general condition of the patient. In young, robust persons he removed the ligature on the fourth day, and in old or decrepit persons he allowed it to remain for six days.

P. U. Walther asserted that definitive closure of vessels after ligation takes place within forty hours, and urged that the ligature should be removed after the lapse of this time.

In Germany Victor von Bruns was the next and last to bring the temporary (removable) ligature before the notice of the profes-

sion. He removed the ligature after two or three days, according to the size of the vessel, and supported his claims for the superiority of this method of ligation by the results of a large clinical experience.

Pécot compared the methods of Jones and Scarpa by way of experiment and came to the conclusion that the round ligature, if applied with sufficient firmness to sever the inner coat of the artery, excited adhesive inflammation earlier than if the broad tape ligature were used.

Ponteau attributed great importance to the connective tissue around blood-vessels in the process of obliteration, hence he advised that an abundance of this tissue should be included within the ligature.

Delpech (1777–1832) arose against Scarpa in France, and C. J. M. Langenbeck in Germany. The latter regarded the adhesion of the inner vessel walls of prime importance in effecting a permanent closure, while to the thrombus and lymph coagulum he assigned a less important rôle. The older German surgeons were in the habit of using hemp or linen ligatures. The silk ligature was first proposed in that country by Ph. Fr. von Walther.

For the purpose of preventing the ill effects of the customary ligature a variety of ligature materials was proposed, such as chamois skin by Physik(1814), catgut by Sir Astley Cooper, silkwormgut by Wardrop, elastic rubber strings by Levert, tendons by Paul Eve, human hair by Porta. Metallic ligatures were brought forward as being less irritating than the ordinary ligature; gilt iron wire was proposed by Ollier, fine iron wire by B. von Langenbeck, and silver wire by Wagner and Sims. Levert experimented with all kinds of metallic ligatures, lead, gold, silver and platina, and always obtained primary union of the wound. Metallic ligatures were always cut short and remained permanently in the wound.

Until the end of the eighteenth century the ends of the ligature were brought out through the wound. The first attempts to cut short the ligature and leave it permanently in the wound were made by Lawrence, who, in 1814, published the results of his experience. For ligatures he used fine dentist's silk. According to Samuel Cooper, however, the priority of this procedure should belong to a certain Haire of Essex, who is said to have practiced it in 1786. Hennen adopted the practice in 1813, and within four months

employed it in thirty-four cases without observing any unfavorable results. Delpech and Guthrie also indorsed this practice.

The introduction of antiseptic surgery has, however, wrought the greatest improvement in the ligature, and the founder of antiseptic surgery, Sir Joseph Lister, has also furnished us with the ideal ligature—the aseptic ligature. What has been sought for centuries has at last been found, a ligature which will arrest the circulation with safety and certainty and a minimum amount of traumatism until the process of cicatrization is completed, and when its work is accomplished, will gradually disappear by absorption and substitution.

Since the introduction of the antiseptic treatment of wounds and the aseptic ligature, surgery has received a new impulse, results have been obtained which were never realized before, operations have been performed successfully which were previously beyond the grasp of even the most ambitious, and, more than all, those horrible spectres, hospital gangrene, erysipelas, pyæmia, septicæmia, and secondary hæmorrhage, which haunted the surgeons of only fifteen years ago by night and by day, have almost completely disappeared from hospital as well as private practice. For all this we are indebted to Lister.

A variety of other animal tissues have been prepared into ligatures and made aseptic, and have been recommended at different times as substitutes for the catgut ligature. Among them we may enumerate silk, silkwormgut, whale and deer tendon, peritoneum, coats of blood-vessels, and nerve tissue. With the exception of the first two, all of these ligature materials, if rendered perfectly aseptic, will, after a certain time, undergo absorption, but it is questionable if any of them possess any advantage over well-prepared catgut. Czerny is entitled to a great deal of credit for the improved silk ligature. He has demonstrated that when silk is made perfectly aseptic by boiling and immersion in carbolized water, it can be safely left in the tissues, where it becomes encysted.

II. Histology of Blood-Vessels.

For our purpose it is not necessary to give a complete description of the minute anatomy of the blood-vessels, but a brief allusion to the arrangement and relations of the histological elements is necessary in order to study the process of cicatrization after ligation;

reference will, therefore, be made only to vessels of a size requiring ligation. Our present knowledge of cicatrix formation in blood-vessels we owe largely to a better understanding of the structure and functions of the coats of the vessels on the one hand, and to laborious researches concerning tissue regeneration and inflammatory tissue formation on the other. As arteries have been made the object of experiment more frequently than veins, we shall give a description of the arterial coats; and, with but few unimportant exceptions, all that can be said of the structure and obliterating processes in arteries will apply with equal force to veins.

The arteries are cylindrical tubes of uniform diameter between their branches. The importance of their function demands that they should occupy localities affording the greatest security against injuries from without and diseased processes within the body. In man the anatomical protection against injury and disease of the arterial system exists in a wonderful degree of perfection, the vessels, as a rule, being deeply situated in the concavities, depressions, and channels of bone, on the flexure side of joints, protected by dense fascia, supported by muscles, and, where the location demands it, surrounded by a soft cushion of adipose tissue; as an additional medium of protection and source of nutrition they are accompanied throughout by a sheath of connective tissue, which connects them loosely with the surrounding tissues.

The blood-vessels are a product of the mesoblast, and are composed of unstriped muscular fibres, elastic tissue, connective tissue, and endothelium. From an anatomical, physiological, and, I may add, pathological standpoint, it has been customary to distinguish three coats, called respectively, according to their location: 1. Internal or Intima; 2. Middle or Media; 3. External or Adventitia. In the larger arteries these coats can be separated and recognized without the aid of the microscope.

1. Intima.

The intima is a delicate hyaline elastic membrane. In the larger arteries it is composed of a single layer of flat endothelial cells, a delicate layer of longitudinal bundles of connective tissue, and a network of elastic tissue. His applied the term endothelium to the pavement epithelium lining the inner walls of the blood-vessels, lymphatics, and serous cavities, to distinguish it from the other

varieties of epithelium. As found in the vessels, Auerbach named it perithelium, and Frey suggested the simple name of primary vessel tunic. The endothelial layer is composed of elliptical or irregular polygonal cells, which are often elongated into a lanceolate shape, being continuous with the endocardium on the proximal, and the capillary vessels on the distal side. The shape of the cells is greatly modified by the degree of the distention of the vessel. The nucleus is oval, its long axis, like that of the cell, corresponding to the longitudinal direction of the vessel.

In the fresh state the contour of the cell is very faint and exceedingly difficult to trace without the assistance of staining. A one per cent. solution of nitrate of silver, as first suggested by Von Recklinghausen, stains the cement substance a dark brown, which imparts a well-defined outline to the irregular margins of each individual cell. If the protoplasm be at the same time stained with chloride of gold, the picture is at once rendered beautiful and perfect, illustrating the cell and its contents to perfection. The cement substance surrounding each individual cell is a lifeless substance, closely allied to the basis substance of the connective tissue, but it is not glue-yielding.

Some histologists (Heitzmann, Stricker, Klein) describe a network of living matter within the cell which sends delicate conical offshoots through the cement substance, thus forming a living reticulum, which connects the individual cells and permeates the lifeless cement substance in every direction. These projections were first seen and described by Max Schultze. According to Heitzmann[1] these living prolongations are capable of producing new tissue elements. The stomata or stigmata in capillary vessels are slight defects in the irregular outlines of the cement substance, and are supposed to permit the passage of the morphological elements of the blood more particularly when in a condition of inflammation. "The attachment of endothelia to the subjacent connective tissue is either direct, by means of delicate filaments penetrating the rim between the feet of the endothelia and the neighboring fibres of connective tissue; or it is indirect by means of an intervening basement layer."[2]

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[1] Microscopical Morphology of the Animal Body in Health and Disease. New York, 1883.

[2] Ibid, page 318.

The outer surface of this basement membrane in many instances is found to be covered by a layer of flat, polyhedral cells discovered by Czerny by means of silver staining. These cells may be regarded as endothelia. These endothelial or endothelioid cells may bear important relation to the subject of regeneration of endothelia. Frey[1] acknowledges that we are as yet ignorant concerning the reproduction of endothelia, while Wendt[2] attributes to the vascular endothelia the still higher function of being converted into elements identical to leucocytes after separation by desquamation. This process has been actually observed by Altmann in the serous endothelia of the exposed mesentery of a frog.[3] The absence of a direct blood supply does not appear to deprive them of a nutritive supply sufficient for their own nourishment, which imparts to them the power of reproduction and which enables them to assume an active part in various pathological processes.

In large arteries immediately underneath the lining endothelium, there is a special connective-tissue membrane variously designated as striated internal coat (Kölliker), innermost longitudinal fibrous coat (Remak), and internal fibrous coat (Eberth). In the adult this layer is distinctly fibrillated. Embedded in this membrane are lodged numerous branching corpuscles, containing large, conspicuous nuclei and so-called granulation bodies. Wendt regards the granulation bodies as matrix-cells for the regeneration of desquamated endothelia. Talma has described similar bodies, but regards them as the product of endothelia, instead of *vice versa*. This inner connective-tissue membrane is prolonged into the smaller arterial branches, a single layer of branched cells being interspersed between the endothelial lining and the elastic membrane of the intima. The elastic membrane of the intima consists of a network of longitudinal fibres. In the larger arteries this membrane is laminated, the lamina being longitudinal fenestrated elastic membranes, between which pass longitudinal networks of elastic fibres.

2. Media.

The middle coat consists of unstriped muscular fibres, elastic

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[1] Handbuch der Histologie und Histschemie des Menschen. Leipzig, 1874, p. 147.

[2] The Blood-vessels. Satterthwaite's Manual of Histology. N. Y. 1881.

[3] Archiv für Mikrosk. Anatomie, vol. xvi. p. 3.

and connective tissue. In vessels of small or medium size, there is a preponderance of muscular over elastic elements, in the larger trunks the reverse condition obtains. The muscular tissue consists of smooth nucleated muscle fibres arranged in concentric layers, and disposed transversely or obliquely around the vessel. Bardeleben maintains that an inner longitudinal muscular coat exists in all large and middle-sized arteries. The muscular elements are arranged in layers or groups, the interspaces being occupied by connective tissue and elastic fibres arranged in networks. The complicated relations of the elastic fibres in this coat have caused no little confusion in giving a description of it.

Henle describes four distinct layers. The middle coat is distinctly separated from the intima by the interposition of the internal elastic coat. The external elastic coat of the media consists of a close network of delicate elastic fibrils anastomosing with similar reticula from the adventitia. The third layer of the elastic tissue fills the interspaces between the muscular layers in the interior of the middle coat. A small amount of connective tissue is found in this coat, usually accompanying small blood-vessels when they permeate it. The elastic fibres are usually arranged transversely to correspond with the direction of the muscular fibres, but some of them, especially those in immediate contact and intimately connected with the fenestrated membrane of Henle, are arranged in a longitudinal direction. The great degree of elasticity possessed by the arterial coats is, as a rule, wrongly attributed entirely to the existence of the elastic tissue; Hyrtl[1] very properly remarks that all of the tunics share this property in common with the elastic tissue, otherwise the remaining tissues would suffer a certain amount of distraction during the expansion of the vessel.

The circular direction of the muscular fibres, and the same direction of the bulk of the elastic fibres of the middle coat, predispose to the laceration of this coat in ligating an artery by means of a round ligature when firmly applied; but, as some of the fibres are arranged obliquely and longitudinally, complete division seldom occurs, and only on the application of considerable force. The principal elements of this coat, in common with the same tissues in other localities, in case of injury or disease affecting their structure, do not

[1] Lehrbuch der Anatomie des Menschen, Wien, 1878, p. 140.

possess the power of reproduction or regeneration. The loss of tissue is filled in by cicatricial tissue, and solutions of continuity are invariably repaired by connective tissue.

3. Adventitia.

The external coat, the adstitia of Haller, is the simplest in structure, being composed of interlacing bundles of connective tissue, commingled with elastic lamellæ of varying thickness. The external coat serves as a nidus for the nutrient vessels, the vasa vasorum. These vessels arise from the trunk which they supply only in exceptional cases (Henle), but are usually recurrent vessels from the nearest branches. Hyrtl has called attention to the fact, that even the smallest of these vessels is accompanied by two veins. He has never seen these vessels extend beyond the adventitia. Frey asserts that the media receives vessels from the adventitia. In the outer coat the vessels resemble the capillaries in the connective tissue, but form a more dense vascular network.

Klein locates the vasa vasorum as follows: "The media and adventitia of large vessels (arteries and veins) contain a special system of nutrient blood-vessels, vasa vasorum; the arterial and venous branches of these lie chiefly in the adventitia, occasionally also in the part of the media; the capillaries generally penetrate into the media and near the intima, only seldom also into the latter (Köster). In the microscopic arterial branches we meet with capillary vessels, as a rule only in the adventitia."[1]

Flint says: "A tolerably rich plexus of vessels is found in the external coats of the arteries. These are called vasa vasorum, and come from the adjacent arterioles, having no direct connection with the vessel on which they are distributed. A few vessels penetrate the external of the middle coat, but none are ever found in the internal coat."[2]

Lymph-spaces are present as intercommunicating interfascicular spaces, containing connective-tissue cells, in all coats of arterial and venous trunks. Most histologists take it for granted that the ultimate distribution of nerve filaments from the cerebro-spinal centres and the sympathetic, reach only the adventitia and media. Cohnheim's

[1] Atlas of Histology, Phila. 1880, p. 143.

[2] The Physiology of Man, N. Y. 1866, vol. i., p. 245.

researches, however, tend to prove that the finest axis fibrilli of the nerves terminate in the epithelial layers. The termination was described by some observers as a plexus between the epithelia, while others (Pflueger, Flemming) claim that the axis fibrilli penetrate the body of the epithelium and may terminate in its nucleolus. Heitzmann has traced the terminal filaments into the cement substance between the epithelia. From the foregoing anatomical consideration, it is evident that the intima, although devoid of blood-vessels, yet receives sufficient nutritive supply to render it capable of regenerating its own elements in case of loss, and of assuming inflammatory changes under the same circumstances and in the same manner as other tissues occupying the same relative position to the vascular system.

I will append a short abstract of the microscopical description of veins as given by Raab as an introduction to his paper "On the development of the cicatrix in blood-vessels after ligation." His studies were made on veins of dogs. On making a longitudinal and a transverse section through a vein, the endothelial cells appear as an exceedingly delicate seam which, from the greater prominence of the nuclei towards the lumen of the vessel, presents a slightly wavy appearance. The endothelial cells are not in direct contact, but each is surrounded by a zone of cement substance which fastens the cells among themselves and to the subjacent tissue. This cement substance, according to Julius Arnold, is a remnant of the protoplasm from which the original cells were formed. The nucleus containing a number of nucleoli is located near the centre of the cell. On section, this nucleus presents the outlines of a half ellipse, the long axis of which is in contact with the vessel wall. The distance between two nuclei of neighboring cells amounts to three or four times their longest diameters, and from this it is easy to estimate the area of a protoplasmic plate.

As carmine stains only the nucleus, the contour of a cell can only be traced after staining the specimen with nitrate of silver. The endothelia are either rhomboidal or polygonal in shape. Isolated cells can be obtained in most perfect condition from veins which have been immersed for some time in a one per cent. solution of chloride of sodium, lime-water, or Mueller's fluid. For silver staining, the valves are best adapted; they can be spread on the object glass without any special preparation, and show most beautifully the

mosaic arrangement of the cellular layer. On the outer side of the endothelial lining a framework of elastic tissue is found. The strongest fibres of this network are arranged in concentric rows in regular order, parallel with the long axis of the vein, while the smaller fibres take a diagonal or radiate course. In this elastic network are found bundles of connective tissue crossing each other in all directions. These fibres are very dense immediately beneath the endothelial layer, and are intimately interlaced with the elastic tissue; towards the periphery they are more loosely arranged.

The elastic membrane, which in the arteries completely separates the endothelial from the muscular layer, does not exist in the veins. In transverse sections of a vein, the longitudinal elastic fibres appear as light, round, or oval objects between the loose wavy connective-tissue bundles, and in the spaces surrounding them an occasional spindle or stellate cell with a large nucleus may be seen. Muscular tissue is not to be found in the superficial cutaneous veins of dogs. It is also absent in the internal jugular and femoral veins. The adventitia consists of loose connective-tissue and firm elastic fibres, separated by a distinct space from the middle coat.

III. Intermediate Ligature, Ligature en masse.

All of the older surgeons were in fear of a too early separation of the ligature, and aimed to prevent secondary hæmorrhage as the result of such an occurrence by including adjacent tissues, thus protecting the vessel against undue pressure. The object of this practice was simply to apply the ligature as a provisional mechanical agent to arrest the flow of blood in a vessel, without any theory as to the permanent closure of the vessel. The ligature was passed underneath, with points of entrance and exit some distance from the vessel, and firmly tied. This method was practiced by Paré, and through his influence and example it was adopted by all of the prominent surgeons until nearly the end of the eighteenth century. Guillemeau, Thévenin, Garengeot, LeDran, Louis, Dionis, and Petit were faithful followers of Paré, and with few unimportant modifications, followed his directions to the letter. Since the definitive closure of vessels has been made an object of study and experiment, this method of ligation has been abandoned and is only resorted to in exceptional cases where isolation of the vessel or vessels is impossible from the nature or location of the wound.

IV. Immediate or Direct Ligature.

The experiments of Jones led the way to the immediate or direct ligature. Jones and his followers placed great stress on the laceration of the inner tissues of an artery by the circular constriction of the ligature, in effecting provisional and definitive closure of the lumen of the vessel. The simple round ligature was gradually adopted by all surgeons who aimed at division of the internal coats by the ligature. The size of the ligature has also undergone considerable modification. Bell used fine oiled ligatures which he supposed would apply themselves accurately to the artery. Some united from two to as many as eight (Arndt) ligatures into one string.

Lisfranc used moderately broad ligatures, but he claimed that in tying the knot they were changed into round cords and would as effectually divide the inner coats as the round ligature. Velpeau used ligatures proportionate in size to the vessel to be ligated. Hodgson used the fine round ligature. Lawrence spoke highly of the use of very fine silk, dentist's silk, in tying arteries of any size. A. Cooper was also in favor of the round single ligature. The circular constriction of Jones, with a single round thread, by degrees won the favor of surgeons and firmly maintained its position as the best method of ligation until the advent of the aseptic ligature. The advantages presented by this method during its pre-antiseptic period were: 1. Effective and safe provisional closure of vessel. 2. Promotion of process of definitive closure of vessel. 3. The spontaneous elimination of the ligature by diminishing the amount of tissue included in the loop of the ligature.

V. Scarpa's Aplatissement.

Scarpa's ligature was intended by its author to fulfill the two essential indications in obliterating the lumen of a vessel: 1. To arrest the circulation temporarily by mechanical pressure without lacerating the tissues of the vessel. 2. To approximate and keep in constant and accurate contact a sufficiently large surface of the inner vessel walls for the union to take place by adhesion. His leading idea was that the intima resembled serous surfaces, and only a moderate amount of irritation was necessary for rapid union to take place, and that the injury inflicted by the circular ligature was too

severe to obtain the most desirable result. He used ligatures two lines in width and tied over a small cylinder of linen. The ligature was usually expelled spontaneously about the fifteenth day, but if this was not the case and it was loose upon the vessel, it should be removed at this time. Scarpa's theories found many admirers, who introduced modifications in the operation to suit their individual ideas. Förster substituted for the cylinder of linen, charpie and cork; Deschamps, agaricus; Desault, small plates of wood; Cline, cork; and Roux, small rolls of diachylon plaster.

In England this practice was advocated by Crampton, and in France it was represented more particularly by Boyer and Roux. Some exponents of the theory of aplatissement, while believing in the doctrine, objected to the introduction of foreign bodies into the wound, which they regarded not only as useless but injurious to the healing of the wound. Jameson used ligatures made of strips of raw chamois skin, which he claimed would by their pliability and elasticity hold in approximation the inner vessel walls without inflicting injury to its tissues. Without means to prevent suppuration, it can be readily understood that the expectations held by the originator of this method of ligation and his followers were not realized, and it was by degrees displaced by the round ligature.

VI. Double Ligature.

The double ligature is mentioned by Celsus and Ætius. Rolandus of Parma speaks of the double ligature as applied to the vena organica (jugularis). John Bell and Maunoir not infrequently applied two ligatures in close proximity. In ligating arteries in their continuity, Abernethy always applied the double ligature after isolating the vessel freely, claiming that even if the intermediary isolated portion sloughs the ligatures will successfully guard against secondary hæmorrhage. As an important advantage of this method he mentions that the vessel can be divided between the ligatures, which relieves tension and allows both ends of the artery to retract into the tissues—occupying then the same favorable position as vessels divided during an amputation. The double ligature has been frequently employed in experiments for the purpose of studying the process of cicatrization in blood-vessels after ligature, and will be again referred to in that connection.

According to time, ligatures may be classified into: 1. Momen-

tary; 2. Temporary; 3. Permanent. The first two varieties aim at obliteration of the lumen without loss of continuity of the vessel, while until recently the permanent ligature was always expected to divide the artery before it could be eliminated as a foreign body from the wound.

VII. Momentary Ligature.

A series of experiments on animals made by Jones satisfied him that definitive closure of an artery frequently takes place by drawing the ligature tightly and removing it at once. The rupture of the internal coats in many instances produced satisfactory closure by mechanically interfering with the circulation, and causing the formation of a thrombus, the definitive obliteration following as the natural consequence of the traumatism. To insure these results more constantly, he made several of these circular constrictions in close proximity, so as to inflict a greater amount of traumatism, and procure a larger surface for cicatrization. Jones called attention to the superior advantages offered by this method of ligation over all other methods, as it would secure obliteration of vessels without incurring the necessity of leaving a foreign substance in the wound. Unfortunately, however, the results obtained were so uncertain that he did not dare to recommend its adoption in practice. In many instances, as late as the third or fourth day, the artery was found permeable, a sufficient proof that the operation with all its other advantages lacked reliability.

Porta made fifty experiments with the momentary ligature on dogs, sheep, and goats, with the result that partial or complete obliteration of the vessel by thrombus or lymph-coagulum followed in only ten, while in all of the remaining cases, only division of the inner coats could be demonstrated.

Maunoir attempted to accomplish the same object by different means. He crushed the internal coats of arteries with a forceps of his own construction, and expected the same series of changes to occur in their interior as the result of the laceration of tissue, but his results must have been equally unsatisfactory, as the procedure does not appear to have been adopted to any extent in practice.

VIII. Temporary Ligature.

The temporary ligature was introduced for the purpose of obviating the deleterious effects of the presence of a foreign body in the

healing of a wound, and the process of cicatrization in the blood-vessel. While the ordinary ligature remained for a period of time varying from three to twenty days, it has been argued that the average time necessary for the ligature to remain is much less; hence various contrivances were invented which were intended as substitutes for the ligature, and which could be removed with greater facility after the necessary time had elapsed; such were the pressure forceps designed by Deschamps, Desault, Percy, Assolini, Kœhler, Porter, Billroth, L'Estrange, Richardson, Crampton, Nunnelly, Wolfe, Jeoffresson, and Speir. A similar function and sphere was assigned to the percutaneous acupressure of Middeldorpf, the ansa fili metallici of B. v. Langenbeck, the filo-pressure of Dix, the ansa hæmostatica a tergo of Schmitz, and more recently the removable ligature of V. v. Bruns.

The laborious researches of Jones prepared the way for the temporary ligature. Travers believed with Jones that vessels are obliterated by inflammatory adhesive exudation and union between the inner coats, but affirmed that the inflammatory process requires a longer period of time to secure the requisite firmness in the adhesions. His first experiments were directed towards ascertaining the length of time required for a sufficiently firm adhesion to take place. The experiments were made on the carotid of horses and asses. The ligature was applied either in the form of a loop, or tied over a tape placed parallel with the artery for the purpose of facilitating its removal. The ligature was removed after one, two, and six hours, and the animal killed from twenty to thirty hours after the operation. In fifty per cent. of the cases, where the ligature remained for one hour, the vessel was not obliterated. In all cases where it was allowed to remain from two to six hours, the experiment proved successful. From these experiments he concluded that six hours is the longest time required for the ligature to remain, and that at this time definitive occlusion has always been accomplished.

In order to determine whether the closure of the vessel is perfect at this time, or whether it is effected after the removal of the ligature, he made another series of experiments, dividing the artery on the peripheral side after removing the ligature. These experiments satisfied him that definitive closure takes place *after* the removal of the ligature, and is effected by an exudation of plastic lymph. If the ligature remained for twelve hours, and the artery

was cut on the peripheral side, no hæmorrhage followed its removal. He reduced his theory to practice by ligating the brachial artery in a man suffering from aneurism, and removed the ligature fifty hours after the operation. No hæmorrhage followed, and the patient recovered. He next tied the femoral artery for popliteal aneurism, and removed the ligature twenty-seven hours later. Pulsation soon returned below the seat of operation. The disappointment due to the failure in this case deterred him from giving the temporary ligature further trial, and he returned to the ordinary ligature. This method was tested by a few English surgeons, but, not meeting with more encouraging results, was soon completely abandoned. Scarpa, in Italy, was the next advocate of temporary ligature. His pathological views regarding the use of the ligature and the process of obliteration of vessels, as well as his method of ligation, are given elsewhere.

Delpech claimed that a few days after ligation, the ligature is found loose on the vessel, and consequently can exert no influence for good, and therefore should be removed like any other foreign body, so as not to interfere with the normal healing of the wound.

Velpeau also regarded the temporary ligature with favor. P. U. Walther studied the effects of the temporary ligature on animals. With a ligature instrument of his own device, he aimed to divide the inner coats of the vessel, and removed the ligature after forty-eight to seventy-two hours, when definitive closure was always found perfect.

N. R. Smith constricted the vessels with an iron wire passed through a silver tube, and found arteries of the fourth and fifth size obliterated after six hours. The femoral artery was found permanently closed after two days. Victor v. Bruns originated his method of filo-pressure in 1868.[1] The silk ligature which he used was passed around the artery and brought out of the wound through a silver cannula with a crossbar, to which it was fastened. Arteries of the size of the radial he found closed after eighteen hours, while larger arteries required from one to three days. For six years this method was used exclusively in all cases requiring ligation in Bruns' clinic, with entire satisfaction. Only in two cases did secondary

[1] Paul Bruns, Die temporäre Ligatur der Arterien, Deutsche Zeitschr. f. Chir., B. V., S. 327.

hæmorrhage occur; in one instance the common carotid was ligated during an operation for the removal of a cancerous tumor of the thyroid gland, and the ligature removed on the fifth day; in the second case the femoral was ligated, and the ligature removed on the third day.

The great objections against the temporary ligature have always been, that the wound could not be completely closed, or had to be reopened at the time of removal of the ligature, thus increasing the risks of suppuration, and preventing primary union of the wound, circumstances which the ligature was intended to obviate. Absence of suppuration and primary union of the wound are the most reliable safeguards against secondary hæmorrhage after any method of ligation, and any method which cannot secure these results with some degree of certainty, must be considered as faulty in principle and practice. This can be said without hesitation against the temporary ligature as described above. The aseptic animal ligature must be considered as a temporary ligature in every sense of the word, but the material of which it is composed is removed by healthy active granulations instead of by the hand of the surgeon, an advantage which it would be difficult to over-estimate, and which neutralizes all valid objections against the temporary ligature. The ligature of the future, then, will be the aseptic animal ligature.

IX. Permanent Ligature.

The permanent ligature is composed of a material which will remain for the most part unchanged in the tissues of the body, and is either permanently retained (encysted) or spontaneously expelled. Before the aseptic ligature came into use, the ligature usually cut its way through the remaining tissues of the artery in from three to twenty days, by a process of molecular death, and was spontaneously expelled, thus destroying the continuity of the vessel in every instance.

Hodgson held that the ligature as usually applied, divides the two inner coats of the vessel, and destroys the vitality of the circular constricted portion of the adventitia, which separates like any other slough and comes away in the loop of the ligature. The same explanation is given by Guthrie, Brodie, and Gross. Bruns, however, maintains that the constricted portion under the pressure of the ligature undergoes molecular necrosis, a process necessarily

attended by suppuration. He also claims that in animals, if the ligature is cut short, it cuts through the tissues and is encysted in the cicatrix.

Porta studied experimentally the future fate of ligatures in the wound. He made three hundred experiments, using catgut, silk, hemp, linen, and horse-hair ligatures, cutting them short. The animals were killed from a few days to three years after the operation. Of the three hundred ligatures, sixty-four were completely absorbed; of eighty catgut, thirty-three; of one hundred and twenty silk, nineteen; of fifty linen, ten; of forty horse-hair, two. Of the two hundred and thirty-six ligatures which remained in the wound, only twenty-six were found lodged in abscess cavities. He claimed that the ligature destroyed the continuity of the vessel by interstitial absorption.

P. U. Walther in his numerous experiments with the temporary ligature found the adventitia divided in only one case. He removed the ligatures at variable periods of time, from one hour to one hundred and ten hours after operation. P. Bruns[1] made fifteen experiments to determine the effect of the ligature on the coats of vessels, and confirmed the observations of Walther.

If the constricted portion of an artery is examined some time after the application of the ligature, it is not always easy to determine whether complete division has taken place or not. A few days after ligation, the artery in close proximity to the ligature is thickened, the swelling on each side effacing the depression made by the ligature, and shutting the ligature out of sight. The traumatic peri-arteritis produces a connective tissue proliferation which covers the ligature and both ends of the artery as the provisional callus after fracture surrounds the broken ends of the bone. If the inflammation does not proceed beyond the process of tissue formation, the granulation tissue is converted into cicatricial tissue, which forms an additional connecting medium between the ends of the artery, and by forming at the same time a capsule around the ligature, the latter becomes permanently encysted.

If the end of an artery is tied, the vitality of the ligated stump will depend on the manner in which the wound heals; if suppuration takes place it will in all probability separate as a slough, and

[1] Op. cit.

with the ligature will escape with the wound secretions; if, on the other hand, the wound heals by primary union, it will either remain in organic connection with the vessel and form new vascular communications with the adjacent tissue, or in the event of a cutting through of the ligature, it may still retain its vitality and remain in the tissues, or finally it may be removed by gradual absorption. John Bell and Otto Weber were convinced that the end of the ligated vessel invariably separates and dies. There is, however, good reason to believe that the ligated artery stump in the absence of suppuration will retain its vitality, and will again unite with the surrounding tissues from which it receives its nutrition. P. Bruns made a few experiments in this direction.

Experiment 1. Double ligation of carotid artery of a dog; division of artery between ligatures. The animal was killed, and parts were examined fourteen days after operation. The ends of the artery were separated 2 cm., the interspace was bridged over by a band of connective tissue in which were embedded both ligated stumps a short distance from the closed ends of the artery.

Experiment 2. Vessels and operation the same. The separated ends of the artery were embedded in the intermediate connective-tissue string.

Experiment 3. Femoral artery, operation the same. Local conditions the same, only that the bridge of new connective tissue was larger and firmer. The separated ends of the artery were somewhat reduced in size.

Experiment 4. Femoral artery, operation the same. Separated pieces were much smaller, and incorporated in the newly formed connective tissues.

In all of these experiments it appears that the ligature cut its way through the tissues of the artery, thus completely separating the ligated stumps, and still they retained their vitality through the influence of the surrounding living tissue. The ligatures were undoubtedly drawn very tight, and as the operations were done without antiseptic precautions, the reaction was in excess of what was necessary to obtain obliteration of the vessels. These circumstances will go far towards furnishing an explanation of the uniformity with which the constricted portion of the vessel gave way under the ligature.

The use of the aseptic ligature and antiseptic treatment of the wound tend to preserve the continuity of the ligated vessel, as has been abundantly proved by clinical experience and experimental research. In many of my specimens it can be seen that weeks and months after the operation the ligatures remained in their original

location and occupied the same relative position to the vessel as immediately after the operation, the ligature in every instance where suppuration was prevented being surrounded or encapsuled by a dense capsule of connective tissue. If the end of an artery is ligated under antiseptic precautions, the stump of the artery retains its vitality in a similar way, and is nourished in the same manner as the pedicle after ovariotomy, the only difference being that in the former instance the local conditions are perhaps more favorable for the preservation of the vitality of the ligated parts.

X. Aseptic Ligature.

In his first communication to the profession on this subject Lister alludes to the advantages of the aseptic ligature as follows: "If the antiseptic ligature be employed it merely inflicts a wound or injury upon the vessel, without introducing any permanent cause of irritation. The injured part, therefore, becomes repaired after the manner of a subcutaneous wound without passing through the process of granulation and suppuration, which is induced by the employment of the ordinary septic ligature."[1]

It may now be truly said that some form of aseptic ligature is used at present by almost every surgeon, and that, while the merits of the antiseptic treatment of wounds are still denied by many, few or none would use the ordinary ligature without realizing that their duty towards their patients had not been conscientiously discharged. Perhaps no other surgical procedure has ever enjoyed the confidence of the whole profession throughout the civilized world to the same extent as the aseptic ligature. This universal faith in the reliability and safety of the aseptic ligature is only a natural outgrowth of the superior results following its use. Protracted suppuration in wounds the result of retained ligatures, secondary hæmorrhage, and suppurative inflammation of vessels have been gradually diminishing in frequency, and bid fair under the influence of the aseptic ligature to be almost completely expunged from the future category of wound complications.

Nussbaum very appropriately remarks: "Catgut is withont doubt Lister's greatest discovery."[2] And again: "How pleasant it

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[1] The Lancet, April 3, 1869.

[2] Leitfaden zur antiseptischen Wund-behandlung. Stuttgart, 1879, S. 23.

is to cut the ligatures short and leave them unconcerned to their fate in the wound! In ovariotomies, etc., their value cannot be over-estimated. The manner in which catgut adheres to an artery, forming connections with it and the surrounding tissues, assisting at the same time in forming a firm ring around the coats of the artery, are exceedingly welcome occurrences, guarding against secondary arterial hæmorrhage in ligating in the continuity of a vessel, and rendering even the application of a ligature in close proximity to a large collateral branch devoid of danger. All this silk cannot do."

Before the introduction of antiseptic surgery suppuration at the seat of ligature was almost a necessity. As suppuration interfered seriously with the hyperplastic processes in the tissues of the arterial tunics, secondary hæmorrhage was of frequent occurrence, because the adhesion between the surfaces of the interior walls of the vessel were not sufficiently firm to resist the intra-arterial pressure at the time of the separation of the ligature. It was on this account deemed necessary by the older surgeons in deligating an artery in its continuity, to apply the ligature at least an inch distant from the next collateral branch, so as to favor the formation of a thrombus. The aseptic ligature marks a new era in the surgery of blood-vessels. Ligating a vessel under antiseptic precautions presents the following advantages:

1. The ligature remains undisturbed in the wound, becoming either absorbed or encysted after having fulfilled the purpose of a provisional hæmostatic.

2. Prompt obliteration of the vessel takes place by proliferation of new tissue elements from pre-existing cells independently of the formation of a thrombus; in fact, thrombosis is often wanting. The constricted portion of the vessel does not necrose, it is infiltrated like the catgut with living tissue.[1] Bardeleben makes a similar assertion.[2]

In all operations with the aseptic ligature the small size of the clot and its frequent entire absence is in remarkable contrast with the results observed after the ordinary septic ligature. The importance of the thrombus as an active agent in the definitive closure of vessels has vanished before the brilliant results obtained with the

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[1] C. Hueter, Grundriss der Chirurgie, 1880, B. I. p. 146.

[2] Berl. klin. Wochenschrift, No. 29, 1875.

aseptic ligature. John A. Liddel, in speaking of vein ligature, says: "If a ligature of animal origin, such as carbolized catgut, has been applied the approximated walls grow directly together, and the ligature itself disappears by absorption or is replaced by new connective tissue."[1]

A discrepancy of opinion still exists regarding the time in which the catgut ligature is absorbed. The results of experiments in this direction have not been uniform. Lister ligated the carotid artery of a calf with carbolized catgut, and on examining the parts, thirty days after operation, he found only small portions of the ligature remaining, the rest having been absorbed and its space occupied by new tissue.

Czerny operated on rabbits, and examined the parts from one to thirty days after operation. After a number of days the ligature was always found loose on the vessel, softened and infiltrated with cells. Fillenbaum applied a double ligature to the carotid artery of a dog, and killing the animal fourteen days subsequently, found only microscopical remnants of the ligatures. Schurhardt experimented with guinea pigs, and if the ligature was allowed to remain for five weeks, only traces of it remained.

P. Bruns[2] operated on dogs four times, tying the femoral and axillary arteries, no antiseptic precautions being used, and the specimens were examined after ten days. In two cases the catgut ligatures had undergone but little change; in the third case the ligature could not be detected with the naked eye, but the microscope showed traces of it; in the fourth case a double ligature had been applied to the femoral artery 4 cm. apart, and in this instance the proximal ligature showed no change, while of the distal ligature only the knot remained. He also ligated the carotid artery three times and examined specimens after twenty days had elapsed, and found in only one instance traces of the ligature on making longitudinal section of the vessel. In two cases he examined the ligatures after thirty days, the carotid and axillary arteries being the vessels tied, and found only microscopical traces. In four more operations he tied the axillary and femoral arteries, and examined after forty days, and on careful examination found traces of the ligature only

[1] Injuries of Blood-vessels. The Internat. Encycl. of Surg., vol. iii. p. 211.

[2] Die temporäre Ligatur der Arterien, Deutsche Zeitschr. f. Chirurgie, B.V.

in one case, while in the remaining three the microscope revealed only traces. From these experiments he concluded that the catgut ligature from the first to the tenth day is either not changed at all, or that the changes are not constant; absorption is constant from the twentieth to the thirtieth day, and after the fortieth day only microscopical remnants can be found.

M. Arnaud, in a series of careful experiments, gives these results in regard to the absorption of carbolized catgut ligatures:[1]

Catgut disappeared once in	4 days
" " twice in	7 "
" " once in	9 "
Catgut distinctly visible once in	4 "
" " " " "	9 "
" " " " "	11 "
Catgut visible but softened and infiltrated once in	16 "

The time required for absorption, although variable in the same animals and in the same locality, will depend on: 1. The quality of the ligature; 2. The size of the ligature; 3. The nature of the tissue with which it is kept in contact; 4. The presence or absence of suppuration. P. Bruns claims that catgut is dissolved by pus, hence it will disappear in a shorter time in wounds that suppurate. In my experience I have observed the contrary. In suppurating wounds I have seen the catgut remain unchanged for an exceedingly long time, and after weeks have seen the ligature come away in the secretions, having undergone but little change. The absorption of the catgut ligature is accomplished by a process of softening and infiltration of cellular elements, and is consequently accomplished in the shortest space of time in wounds where the process of granulation is not impaired by suppuration.

The immediate and remote effects of the catgut ligature on the vessel also deserve consideration. The impression prevailed at one time, that the catgut ligature does not destroy the continuity of the artery. This assertion has, however, met with opposition.

P. Bruns,[2] in his experimental work, has made special search in this direction in thirteen ligations of arteries in their continuity. In the three specimens obtained ten days after operation, he found the artery completely severed in one instance, while in the other two

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[1] Richard Barwell, Aneurism, Encycl. of Surgery, New York, voi. iii. p. 442.

[2] Op. cit.

cases a fine thread of adventitial tissue was found in the loops of the ligatures. In the remaining ten cases, where only traces and microscopical remnants of the ligatures could be found, three different conditions of things presented themselves.

In three cases the vessel was completely divided in the same manner as after using the ordinary ligature, but the intermediate space between the vessel ends was less than after using the silk ligature, the space measuring only from 1.5 to 3 mm., and being filled in with connective tissue. In six cases a solution of continuity had apparently not taken place, and its existence was ascertained only by close examination. The place of ligature presented a somewhat prominent circular ring; on making a longitudinal section, the intima and media were found severed, and their margins directed towards the interior of the vessel, shutting off its lumen on both sides by a concave or funnel-shaped end. The interspace between both blunt ends was occupied by a solid intermediary substance about the thickness of the ligature and continuous with the adventitia. The intermediary substance was composed of young connective tissue interspersed with particles of the catgut ligature. In one case the continuity of the vessel was perfect, all of its coats being entire. Evidently the ligature was not tied with the same degree of firmness as in the other cases. The lumen was only narrowed by the ligature and rendered impermeable by a thrombus.

Bruns is willing to admit, that in case the catgut ligature is drawn only sufficiently tight to interrupt the circulation, all of the coats of the artery remain intact during the healing process, and the continuity of the vessel is preserved in the strictest sense of the word. In the cases where division of the vessel took place, and a bridge of connective tissue, corresponding to the diameter of the ligature, formed, he also asserts that *practically* this process may be regarded as similar to the process of healing without loss of continuity of vessel-tunics.

Stimson[1] agrees with Bryant, that the catgut ligature not only primarily divides the two inner coats of an artery like the ordinary silk ligature, but that subsequently the adventitia also gives way under the pressure of the ligature, thus completely interrupting the continuity of the vessel. They affirm that the bridge of interme-

[1] The Antiseptic Catgut Ligature, Am. Jour. Med. Sciences, 1881, p. 131.

diary connective tissue may impart an appearance as though no division had occurred.

The results of my experiments have demonstrated to my satisfaction that it is not necessary to tie with sufficient firmness to divide any of the arterial coats, in order to cause prompt obliteration of the artery, and that in such instances the coats of the vessel are transformed into a solid string of connective tissue, the best possible result which can be obtained after ligature. Even in case the ligature is tied with sufficient force to rupture the inner coats, the constricted adventitia may retain its vitality, and form a part and parcel of the intermediary connective tissue uniting the two ends of the vessel; and still further, if the vitality of the adventitial coat is suspended, and it is removed by a slow process of molecular disintegration and absorption, it is replaced by tissue elements which are converted into a similar tissue, thus practically preserving the continuity of the vessel.

In the event of suppuration, the advantages of the aseptic catgut ligature are lost, and the ligature escapes with the discharges, either entire and unchanged, or in fragments after it has undergone softening and disintegration. Ligatures made of any other animal tissue rendered properly aseptic are disposed of in the wound in a similar manner, and it has not been proved that any of them possess any advantages over the well-prepared catgut ligature.

Mr. Barwell,[1] in tying large arteries, uses a broad ligature made of the strong middle coat of the ox's aorta. His idea is to approximate the intima without rupturing it. In sixteen cases of ligation of large vessels it proved successful. In one case of ligation of the femoral artery, hæmorrhage occurred from a small vessel near the ligature at the time of operation; at the request of Mr. Barwell, two more ligatures were applied within an inch of the first ligature, and the case terminated favorably. Mr. Barwell still maintains the novel belief that his ligature material is not absorbed, but is organized and becomes a part of the living tissue around it.

Aseptic ligatures made of materials which are not capable of being absorbed remain in the wound and are encysted. All of these ligatures are more prone to destroy the continuity of the vessels than animal ligatures, but they do not do so invariably. Czerny's

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[1] International Encyclopædia of Surgery, New York, vol. iii.

silk, for example, which is used next in frequency to catgut, is infiltrated with cellular elements, and, after a long time, is partly absorbed and completely encysted.

XI. Thrombosis after Ligature.

One of the most serious objections against the prevalent doctrine of obliteration of vessels through the instrumentality of an organized thrombus, is the fact that, in many instances, coagulation of the blood fails to take place after tying a vessel with a ligature, and that primary union of its inner walls has been frequently demonstrated without thrombus formation. The conditions which determine intravascular coagulation after ligature are still not well known.

Alexander Schmidt has shown that fibrin as such does not exist in blood, but that it is the product of a union between the two substances, the fibrinogen and paraglobin, under the influence of a fibrin ferment, and he has further shown that fibrinogen is contained in the plasma of the blood in solution, and that the fibrin ferment and paraglobin are a product of the white corpuscles of the blood. Paraglobin and fibrin ferment are set free and can act on fibrinogen only after dissolution of the white corpuscles. Consequently, as long as the integrity of the white blood-cells is preserved, coagulation cannot take place. As fibrin does not pre-exist in the blood, it is the product of chemico-vital changes which take place before and during the process of coagulation. During coagulation the vitality of the morphological elements in the thrombus is lost as the white blood-corpuscles lose their identity, and their protoplasm unites with the fibrinogen contained in the serum, and produces the fibrin. The endothelia lining the intima, as long as they retain their vitality, prevent the spontaneous death of the white blood-corpuscles, and this prevents the formation of fibrin.

Virchow attributed coagulation to the diminished motion or arrest of the current of blood in the vessel, but this cause has been found insufficient in itself to produce a thrombus provided the endothelia retained their normal qualities. Baumgarten has shown that a column of blood can be kept in a fluid condition for weeks within a vessel between two aseptic ligatures. If after several weeks the blood was allowed to escape through an incision in the tied portion

of the vessel it coagulated the same as blood drawn from any other locality, showing that it had not lost its coagulating properties by its long confinement between the ligatures.

This interesting phenomenon can only be explained by assuming that the aseptic ligature preserves the vitality even of the torn inner coats, which successfully prevents loss of vitality of any of the white blood-cells. Some twenty years ago the famous experiments of Bruecke demonstrated that living tissues resist coagulation, and Baumgarten's experiments most beautifully substantiate this assertion. It is a well known fact that coagulation takes place with the greatest degree of certainty and becomes more extensive in proportion to the magnitude of the traumatism inflicted by the ligature, and the degree and extent of the subsequent inflammation.

Until recently the belief prevailed universally that foreign substances introduced into the circulation invariably produce coagulation. This doctrine has also been successfully refuted. Zahn's investigations have demonstrated beyond all possible doubt that coagulation only follows the introduction of substances which have not been properly disinfected. He introduced aseptic pieces of glass and rubber, and never observed coagulation following this procedure.

Hueter, in speaking of thrombosis in veins, refers to our subject as follows: "Whether by following antiseptic precautions the formation of a thrombus can be prevented with the same degree of certainty as in the case of arteries remains an open question. It is certain, however, that septic infections favor coagulation in veins."[1] Of this latter assertion clinical experience furnishes abundant proof. It is more than probable that during the progress of many of the infectious diseases, many of the lining endothelia of the intima are destroyed, and that the white corpuscles coming in contact with dead tissue lose their vitality and produce thrombosis.

But even under the old pre-antiseptic treatment thrombus formation was by no means a constant result after ligation. Walther, in twenty-eight experiments to determine this question, found a thrombus in both ends of the vessel eighteen times. In one case there was no thrombus on either side of the ligature, and in one only on the cardiac side, while in the remaining eight cases the thrombus was found only in the distal end of the artery.

[1] Grundriss der Chirurgie, 1880, vol. i. p. 148.

Porta has made the largest number of experiments to ascertain the relative frequency of thrombus formation after ligature. In two hundred and fifty cases of ligation of large arteries in animals, in which the vessels were examined for this purpose, he found in thirty-five cases no traces of a thrombus, and yet he observed only three cases of secondary hæmorrhage after four hundred ligations.

Schumann[1] made fifty-four experiments on dogs and rabbits in order to study the provisional and definitive closure of vessels after ligature. Thrombus formation had occurred in only 32 per cent. of the cases, and the coagulum in all of these cases was usually small. It is evident from these statistics that thrombus formation after ligature frequently fails to take place, and that in this event closure of the vessel is effected by tissue proliferation from the vessel tunics. It would hardly appear reasonable to assume with Kocher, that in these cases a thrombus so minute in size as to elude detection by the naked eye might still exist, and perform the difficult task of obliterating the lumen of the vessel.

XII. Organization of Thrombus.

By organization of a thrombus we understand that some of its morphological elements retain their vitality and power of tissue proliferation. In this sense the term is used by all authors who have attributed to fibrin, white blood-corpuscles and red blood-corpuscles the property of being converted into connective tissue. If the intra-vascular thrombus possesses this quality, it is certainly an exception to the general rule, as extravasations of blood in any other locality of the body are never known to undergo organization. Under the most favorable circumstances they are destined to succumb to retrograde metamorphosis, leaving eventually nothing but hæmatoidin crystals as landmarks of their former existence.

Serous membranes afford a favorable surface for rapid absorption of blood, so much so that the peritoneal cavity has been utilized for the purpose of performing transfusion of blood. Copious effusions of blood into joints are usually promptly absorbed, leaving no permanent ill results as far as the functions of the joints are concerned. Immense extravasations into the cellular tissue about the seat of fractures, or as the result of other injuries, are completely

[1] Virchow u. Hirsch's Jahresb. vol. ii. 1874, p. 377.

absorbed in a remarkably short time, provided suppuration is prevented. The anterior chamber of the eye, from the peculiar anatomical structure of its walls, is an exceedingly favorable locality for successful tissue transplantation, as has been demonstrated by Dorremal and Goldzieher, and yet every oculist can testify to the fact that extravasations of blood in this locality never undergo organization, but are usually promptly removed by absorption. As an additional factor, it may also be mentioned that the intra-vascular thrombus is located disadvantageously as far as organization is concerned, the intima and media separating it from the nearest vascular supply.

The assertion made by Lister that blood-clots in wounds under the antiseptic treatment become organized, certainly does not correspond with facts. If blood-clots in the interior of the tissues of the body, safely protected from any possible source of infection, invariably disappear by absorption, there is no good reason to believe that they will undergo any other changes when located in wounds. The clot itself is not organized, but simply serves the useful purpose of furnishing a favorable soil for the lodgment and propagation of new tissue-elements from the adjacent wound surfaces. In this sense the organization of the clot is accepted by Volkmann.[1] He believes that the blood-clot between the broken ends of the bone in compound fractures serves primarily the purpose of a soft cement substance which, under the protection of antiseptic precautions, is gradually displaced by substitution, and its space occupied by permanent tissue.

XIII. Formation of Cicatrix in Blood-Vessels after Ligature.

The ligature fulfills a two-fold object: 1. It constitutes the most scientific and reliable provisional hæmostatic, interrupting at once the physiological function of the vessel at the point of application. 2. It brings the vessel walls in mutual contact, and, by maintaining uninterrupted apposition for a sufficient length of time, it induces an active tissue proliferation which is destined to produce definitive obliteration of the lumen of the vessel. The immediate

[1] Die Behandlung der complicirten Fracturen. Volkmann's Sammlung klin. Vorträge, No. 134.

effect of the ligature in arresting the circulation was well known even to those who first resorted to its use, but the secondary changes, the definitive closure of vessels by cicatrization, has been a subject concerning which there has prevailed the greatest diversity of opinion and which still remains a prolific object of study and investigation.

The researches of Jones laid the foundation for an intelligent and rational study of the process of cicatrization in blood-vessels after ligature. Various theories have been advanced which were intended to furnish an explanation of the process of obliteration, or to point out the particular tissue which supplies the material for the cicatrix. The production of cicatricial tissue within the blood-vessels has been attributed to: 1. Adhesive inflammation and plastic exudation at the seat of ligature without reference to any histological changes. 2. Fibrin. 3. White blood-corpuscles. 4. Red blood-corpuscles. 5. Immigration corpuscles. 6. Connective tissue. 7. Endothelia.

XIV. Formation of Cicatrix by Adhesive or Plastic Inflammation.

The existence of adhesive inflammation has always been recognized as an important element in effecting permanent closure of a vessel after ligature. Under this head will be mentioned the pathological views of older writers who studied the process of cicatrization independently of any accurate histological knowledge.

Celsus believed that the definitive obliteration of the vessel was due to retraction of the artery and tumefaction of the connective tissue around it. Galen asserted that permanent closure takes place by a cicatrix which closes the wound in the vessel, believing that the arterial walls unite only in exceptional cases. Ponteau regarded the inflamed para-vascular tissue as the most important element in the obliterating process. John and Benjamin Bell believed that an artery is occluded by a plastic exudation which takes place from its inner walls and the divided ends.

Scarpa, who compared the tunica intima with serous membranes, and attributed to it the same tendency to assume inflammatory changes and form speedy and firm adhesions, commits himself on

this subject as follows:[1] "The union of the two opposite sides of an artery, as I have mentioned several times, only takes place by means of the adhesive inflammation, to excite which, and in order that it may produce the desired effect, it is necessary that the artery be not insulated too much, or beyond the limits of the ligature; that the degree of pressure be such as to put and keep the two opposite sides of it in complete and firm contact; that the irritation caused by the pressure be sufficient to produce inflammation in the proper coats of the artery without their passing immediately into a state of mortification from a want of vitality. If this degree of pressure be too small, the artery does not inflame sufficiently and is not obliterated, but is rather wasted slowly and then bursts; if the pressure be too great, and especially upon an artery insulated in a greater space than is requisite for the ligature, it mortifies, ulcerates, and opens before the sides of it have adhered to each other, both at the place of ligation and for a certain space above and below it."

Porta placed great stress on the importance of primary union of the wound, and the appearance of an external plastic ring at the seat of the ligature, in securing permanent occlusion of a vessel. He also pointed out how suppuration would interfere in obtaining the most favorable results after ligation. Jones and Travers almost ignored the importance of the thrombus in effecting closure of a vessel, and assigned to the traumatic inflammatory exudation almost exclusively the function in accomplishing this object. They claimed that the ligature acts as an irritant to the walls of the vessel, plastic exudation taking place into its lumen, the torn intima and media becoming adherent, thus permanently closing the canal.

Kirkland and White maintained that the coats of arteries near the ligature unite by plastic lymph, and that the coagulum is not only useless but may prove detrimental by interfering with such union.

After Virchow in his researches on thrombosis and embolism had demonstrated that the intima is not susceptible of inflammation, pathologists again turned their attention to the importance of the thrombus as an active agent in the process of cicatrization. Rokitansky,[2] in opposition to Virchow, again claimed that the final oblitera-

[1] A Treatise on the Anatomy, Pathology, and Treatment of Aneurism, trans. by Henry Wishart, 1808, p. 277.

[2] Handbuch der Speciellen pathologischen Anatomie. Wien, 1844, p. 616.

tion of an artery could take place without a thrombus, in a similar manner as in the vessels of the umbilical cord and the ductus Botalli.

Ph. von Walther[1] says that the tunics of injuried arteries inflame in a similar manner as other wounded organs. The phlogistic exudation takes place first in the external coat, somewhat later in the middle coat, and last on the free surface of the internal tunic.

Cruveilhier, Castleman, and Förster also ignored the importance of the thrombus, and pointed to the tissues of the vessel-walls as the active agents in the obliterating process. All of the authorities who mention adhesive inflammation as the means by which vessels are permanently closed, assign to the thrombus only an unimportant or entirely passive rôle, but at the same time they do not point out the particular tissue element which is supposed to furnish the material for the cicatrix.

Later researches have aimed to limit the process to some special structure and to study and demonstrate the minute processes by which obliteration is accomplished. In one of our recent American text-books on surgery, the process of obliteration in an artery is described as follows: "The permanent closure and final and complete obliteration of these vessels (arteries) is effected by their continued contraction, by the effusion of fibrin within and around the vessels, and at length by the conversion of all their coats into simple cords of connective tissue. Even these latter may in the course of time disappear."[2]

XV. Formation of Cicatrix from Fibrin.

All pathologists who ascribe to any of the pre-existing morphological elements of the thrombus the active part in the process of cicatrization, as a matter of necessity consider the presence of the thrombus essential in the process of obliteration.

John Hunter maintained that the fibrin in the clot is capable of undergoing organization, and is the active agent in producing permanent closure of a vessel after ligation. He based his assertion on the examination of a thrombus taken from a crural artery, which he injected from the lumen of the vessel and found that it contained a network of vessels. To satisfy himself that organization of the

[1] System der Chirurgie. Carlsruhe u. Freiburg, 1843. B. i. p. 253.
[2] Hamilton, The Principles and Practice of Surgery, 1879, p. 176.

thrombus takes place, he applied a double ligature to the carotid artery of a dog, and on examination of the specimen some time afterward he found his conclusion verified.

Gendrin, who repeated the experiments of Hunter, says: "If a quantity of blood is included between two ligatures in an artery or vein, it coagulates, and, as is well known, the serum is absorbed and a slight imflammation takes place in the walls of the vessel. The different parts of the thrombus are decolorized, a thin layer of coagulated lymph diffuses itself over the inner walls of the vessels which effects adhesion between thrombus and vessel-walls, the thrombus finally undergoes organization and cicatrization."

Andral supposed that he had demonstrated in a satisfactory manner that fibrin in cases of pleuritic exudations and pseudo-membranes is converted into connective tissue, and his teachings were generally accepted. Henle also claimed that fibrin is converted into connective tissue, and that it constituted the most important element of the thrombus. Zwicky, a pupil of Henle, was the first to give an accurate microscopical description of the appearances in vessels after ligation. In accordance with the views of his preceptor, he asserted that the blood corpuscles play only a passive part in the process of organization of the clot.

As late as 1872, Billroth writes: "Coagulated fibrin may, by aid of cells, be transformed into connective-tissue inter-cellular substance, although I cannot decide whether this be due to a true metamorphosis, or to a gradual substitution of cell protoplasms for disappearing fibrin." [1]

It is almost unnecessary to say that at the present time no one can be found who claims that fibrin is capable of being transformed into connective tissue, but that wherever found, it invariably disappears after a time by molecular disintegration and absorption. Physiology teaches us that fibrin does not pre-exist in living blood, but that it is formed as the result of chemico-vital changes during coagulation, hence we would, *a priori*, conclude that such a substance is not capable of being elaborated into tissue endowed with a higher degree of vitality.

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[1] General Surgical Pathology and Therapeutics, trans. by C. E. Hackley, New York, 1872.

XVI. Formation of Cicatrix from White Blood-Corpuscles.

After Virchow had shown that adhesive inflammation of the intima is incompatible with its structure, pathologists again turned their attention to the thrombus as the active medium of the process of obliteration. The organization of the thrombus now became a favorite study. Stilling and Zwicky not only claimed that the thrombus undergoes organization, but they were also among the first to describe a vascular network in the thrombus; the vessels, according to their observations, communicating with and originating from the lumen of the vessel.

Virchow, Billroth, and O. Weber referred the organization of the thrombus to the presence in it of the white blood-corpuscles. Czerny and Schumann attributed it to the same cause. They traced step by step the part taken by these corpuscles in the process of organization of the clot. Pirogoff, Thierfelder, Gerstäcker, and Boner, studying the fate of the white blood-corpuscles in subcutaneous tenotomies, found them capable of transformation into new connective tissue.

The conclusions at which O. Weber arrived may be summarized as follows:

1. The red blood-corpuscles and fibrin of the clot disintegrate and disappear by absorption.

2. The colorless blood-corpuscles in the clot, a few hours after the application of the ligature, enter into a transformation into spindle-shaped cells.

3. After a few days the projections thrown out by these cells may be seen to unite with each other, and, by arranging themselves in rows, plainly assume the shape of new vessels.

4. The youngest vessels are formed in the peripheral portion of the clot.

5. During the third and fourth weeks the vascularization of the thrombus is completed, the vessel having formed anastomoses with the vasa vasorum of the adventitia. At the point of ligature where the intima and media have been lacerated, the vessels of the adventitia enter the thrombus directly; further from the ligature they penetrate through the two inner coats and enter the thrombus.

6. About the fiftieth to the sixtieth day the thrombus is traversed everywhere by vessels, more especially at the periphery. A large vessel is often found in the centre of the clot.

7. During the process of cicatrization, the vessels in the thrombus disappear, the lumen of the vessel becomes narrower, and is finally completely obliterated.

8. The cicatricial tissue is the exclusive product of the white blood-corpuscles.

9. The white blood-corpuscles multiply very rapidly by segmentation.

10. The endothelia of the new blood-vessels in the thrombus are produced exclusively from the white blood-corpuscles.[1]

Kocher[2] has studied the organization and vascularization of the thrombus after ligature, and sustains the views entertained by Weber. He injected the vessels from the lumen of the artery, and examined transverse sections under the microscope.

I will give the description of one of his specimens: On December 24, 1867, he ligated the right carotid artery of a dog, and dusted finely powdered cinnabar over the exposed portion of the vessel to indicate subsequently the exact location of the ligature. The animal was killed January 11, 1868. The operation wound was healed. The vessel was injected with gelatine stained with Berlin blue, and hardened at first in a solution of chromate of potassa, and afterward in alcohol; when it was sufficiently hardened, it was thoroughly dried and inclosed in a coating of paraffin for the purpose of making microscopical sections. The decolorization of the thrombus was more complete near the ligature than towards the free lumen of the vessel. The proximal end of the thrombus was adherent only to one side of the vessel, so that the injection material penetrated the other side between the vessel-wall and the thrombus.

From the free surface of the central end of the thrombus a central vessel of considerable size was seen to enter the thrombus; from it smaller vessels branched off and penetrated the thrombus in different directions, forming a beautiful network of capillary vessels, which left no doubt in his mind that the channels were real blood-vessels and not an artificial product. Wherever the thrombus was adherent to the intima, the latter showed small vessels from the adventitia, while the free surfaces of the intima remained non-vascular. Nearer the ligature the vascular network from the adven-

[1] V. Pitha u. Billroth's Chirurgie, i. 1.

[2] Ueber die feineren Vorgänge bei der Blutstillung durch Acupressur, Ligatur und Torsion, Archiv f. Klin. Chirurgie, B. xi. S. 660.

titia was more fully developed, supplying numerous branches to the inner coats of the artery. The torn intima at the seat of ligature was arranged in folds, its free and irregular margins sending prolongations into the thrombus. The media was also divided by the ligature, so that the thrombus penetrated between its fibres. While the vascularity of the vessel-wall increased towards the ligature, the vessels in the thrombus became smaller in the same ratio, disappearing completely near the ligature.

These appearances satisfied him that the vascular supply of the thrombus is derived directly from the free lumen of the vessel, while the vasa vasorum increase in size and number, and distribute branches to the inner tunics over an area corresponding with the adherent portions of the thrombus. He agrees with O. Weber that canalization of the thrombus initiates organization. He also made a number of experiments where the conditions for thrombus formation were exceedingly unfavorable, by tying arteries in close proximity to a large collateral branch. In all cases where the experiment proved successful, he found the two inner tunics ruptured, and in every instance no direct union of the lacerated tissues, but cicatrization was always the result of a thrombus, which in some instances was exceedingly small, almost microscopical in size.

For the purpose of proving that the tissues of the arterial coats take no active part in the process of obliteration, he made the following experiment: The right carotid artery of a dog was tied December 24, 1867, in two places, 2 cm. apart, the blood in the intermediate space having been squeezed out between two fingers before tying the peripheral ligature. Cinnabar was dusted over the vessel in the wound. The animal was killed January 11, 1868. The wound was healed. The vessel on the cardiac side was closed by an extensive adherent thrombus. Between the ligatures the vessel contained a very small adherent thrombus, the greater portion of the lumen being empty. Transverse section through this portion of the artery revealed the star-shaped lumen of the vessel, the folds of the intima being in contact but not adherent. No proliferation of the vessel-wall or the epithelium could be observed. The staining material was found diffused in the para-vascular connective tissue and the outer layers of the adventitia, but had failed to reach the inner tunics or lumen of the vessel. This experiment convinced

him that the intact vessel-wall does not participate in the obliterating process.

His numerous acupressure and torsion experiments showed that wherever obliteration of the vessels takes place it is due to injury done to the intima, however slight that may be, followed by thrombosis, vascularization, and organization of the thrombus, and cicatrization by transformation of the white blood-corpuscles into cicatricial connective tissue, which finally approximates the inner vessel-walls, and holds them in permanent contact. He denies the possibility of direct union between the surfaces of the intima without the intervention of a thrombus. The views so strongly advocated by Virchow, O. Weber, and Kocher have been indorsed for the last forty years by a majority of the most prominent pathologists, and have found their way into most of our text-books.

Paget writes: "The artery between the ligature and the nearest collateral branch contracts and in some instances obliterates the whole portion of the vessel, losing its anatomical features, and is gradually converted into a fibrous string. The colorless blood-corpuscles in the clot elongate into spindles, or form stellate corpuscles, such as are seen in young connective tissue, forming by anastomoses a network which traverses the clot in all directions."[1]

Paget, however, recognises the part performed by the vessel-walls, as he further states: "The clot, with the aid of the plastic inflammatory exudation, becomes firmly adherent to the inner walls of the vessel." Billroth, after his description of organized thrombi, accounts for the presence of the embryonal connective-tissue cells in the following manner: "After having abandoned the idea of proliferation of stable tissue-cells in inflammation, we can no longer talk of a proliferation of the intima in the old sense. But whence come, then, these newly formed cells? I have no doubt that they originate from the white blood-cells, which have been partly inclosed in the thrombus, partly may have wandered into it, according to the observations of Von Recklinghausen and Bubnoff."[2]

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[1] Lectures on Surgical Pathology, 1870.

[2] General Surgical Pathology and Therapeutics, trans. by C. E. Hackley, A.M., M.D. N. Y. 1872, p. 108.

XVII. Formation of Cicatrix from Red Blood-Corpuscles.

The remaining pre-existent histological elements in the thrombus, the red blood-cells, have been considered by the preceding authorities, as passive elements dêstined to undergo granular degeneration and to disappear by absorption. A few pathologists, however, among them Rindfleisch, Adreef, and Koslowsky, assign to them an active part in the organization of the clot, for the reason that they have observed that instead of undergoing molecular disintegration they gradually lose their coloring material, and by a series of successive changes they are transformed into white blood-corpuscles and become endowed with all the intrinsic vital properties possessed by these elements. They maintain for the red blood-corpuscles the same active rôle in the organization of the clot and the process of cicatrization that has been assigned to the white blood-corpuscles.

XVIII. Formation of Cicatrix from Immigration Corpuscles.

Soon after the discovery of the wandering corpuscle this element was supposed to be the principal agent in the process of tissue regeneration and in the formation of pathological products. The obscure and much vexed question of obliteration of vessels after ligation found a ready interpretation by assuming that these wandering corpuscles, endowed with inherent properties to produce new tissue, would penetrate the walls of the vessel and enter its lumen, and there, by being converted into connective tissue, would effect definitive closure. The functions previously attributed to the pre-existing white blood-corpuscles in the thrombus were now assigned to immigration corpuscles by a number of observers.

Von Recklinghausen adopted this theory, and was soon followed by one of his pupils, Bubnoff, who wrote a long and interesting article on this subject.[1] In order to prove that cells enter the vessel from without, he tied the jugular vein in animals, and applied finely powdered cinnabar to the vessel at the seat of ligature before closing the wound. From the well-known capacity of the white blood-corpuscles to absorb finely divided substances, he expected that they would absorb some of these minute granules of the coloring material

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[1] Ueber die Organization des Thrombus, Centralblatt für die Medicinische Wissenschaften. No. 48. 1867.

and convey them into the vessel, which would, on subsequent examination, render their identification in the lumen an easy matter, and furnish positive proof of their passage through the vessel walls. He was not disappointed in his expectations, as in all of his experiments he found on microscopical examination corpuscles charged with granules of cinnabar in the interior of the vessels.

His results lead him to adopt the following conclusions: The colorless blood-corpuscles in the thrombus lose their property to migrate after coagulation has taken place, consequently they take no active part in cell-proliferation. The organization of the thrombus is, to a great extent, accomplished by cells which enter the veins from without. Most of the cells are derived from the vasa vasorum and the adjacent para-vascular spaces. Kocher repeated these experiments on arteries, but failed to obtain the same results.

Thiersch objects to the conclusions advanced by Bubnoff, claiming that the discovery of cells containing granules of cinnabar in the interior of the vessels is no proof that the cells entered from without, as the coloring material might have entered the vessel with fluids passing through spaces in the vessel-walls, without the assistance of any morphological elements.

Raab admits that leucocytes do penetrate the coats of veins, but does not believe that they take any part in the obliteration of the vessel. Durante, Cornil, and Ranvier have demonstrated that leucocytes traverse the walls of a vessel only when this has been tied with a double ligature, causing death of the included vessel, and that leucocytes travel only through this dead tissue. Klein[1] claims that endothelial cells are converted into leucocytes, and that these are instrumental in the process of cicatrization.

Seuftleben[2] has demonstrated beyond all doubt that leucocytes do enter the walls of veins which have been separated from all vascular connections. He removed sections of veins, disinfected them thoroughly, tied both ends firmly, and introduced them into the peritoneal cavity of living animals. He killed the animals at variable periods after the operation and found these bloodless transplanted pieces of vein-tissue in most instances adherent and encysted. Even

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[1] The Anatomy of the Lymphatic System, London, 1873, I.

[2] Ueber den Verschluss der Blutgefässe nach Unterbindung, Virchow's Archiv., B. 77, S. 421.

after a comparatively short time he found the interior of the vein occupied by masses of epithelial cells, spindle-shaped cells, round and even giant cells. The last mentioned cells were evidently intended to accomplish the work of absorption of the transplanted tissues. To all of these cells Seuftleben assigned an extra-vascular origin.

N. Schultz[1] studied the influence of the migration corpuscles in cicatrization in blood-vessels by applying a double ligature and excluding the blood from the intermediate portion of the vessel. He operated on arteries. In examining specimens a short time after operation, he scraped the intima, and observed incipient degenerative change in the endothelia and no attempt at proliferation. In specimens two days old he found white blood-corpuscles in the lumen of the intermediary portion of the vessel, which he believed entered from without, and which were eventually converted into connective-tissue. In specimens one hundred and twenty-eight to one hundred and fifty-five days old, the vessel between the two ligatures consisted of a string of loose connective-tissue in which no trace of the original tissues of the arterial coat remained. Cicatrization progressed more rapidly in the femoral than in the carotid arteries. In one case where only one ligature was applied he also observed no proliferation on the part of the endothelial cells, but in this instance he believed that the process of organization and cicatrization of thrombus was due to the presence of the white corpuscles in the thrombus.

Uhle and Wagner[2] credit the wandering corpuscle with at least a part of the work required in the obliteration of a vessel. Their description of the cicatrix formation commences with the following allusion to this subject: "The organization of a thrombus is certainly not effected by an exudation on the inner surface of the walls of a vessel, nor by the white blood-corpuscles contained in it; perhaps at least in part it is due to the white blood cells circulating in the blood, and which gain entrance into the vessel from the vasa vasorum, or by cells which originate outside of the vessel walls, and by permeating them enter the lumen of the vessel." Billroth, after speculating on the origin of the white blood-corpuscles, says that they may

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[1] Ueber die Vernarbung von Arterien nach Unterbindungen u. Verwandungen. Deutsche Zeitschr. f. Chir. ix.

[2] Handbuch der allgemeinen Pathologie, Leipzig, 1876.

spring from connective-tissue or a protoplasm analogous to connective-tissue, and he believes that they may traverse the living walls of vessels, as he has performed Bubnoff's experiment successfully on the carotid artery of a dog.

One of the strongest arguments in favor of the tissue-producing function of the wandering blood-corpuscles is advanced by Ziegler.[1] His experiments consisted in introducing, under antiseptic precautions, into the living tissues of animals, two glass plates with a capillary space between them. On examining the specimens at different intervals of time he found the space between the glass plates at first filled with white blood-corpuscles, which were subsequently transformed into connective tissue and blood-vessels. The results of these experiments have made Ziegler an ardent advocate of the doctrine that the wandering corpuscle is the principal tissue-producing element in all regenerative and pathological formations.

Every one must admit that these experiments are both ingenious and beautiful, but the deductions may lead to erroneous conclusions, as the experiments do not preclude the possibility of the entrance of embryonal connective-tissue elements from the wounded surfaces surrounding the glass plates. In many instances the obliterating process is accomplished in such a remarkably short time that this theory would hardly apply, and until more positive evidence is furnished we must seek for a more satisfactory explanation.

XIX. Formation of Cicatrix from Endothelia.

The majority of the older authors who maintained that direct and primary adhesion of the inner walls of the vessel takes place after ligature, attributed this occurrence to a plastic exudation upon the free surface of the intima. In entertaining this idea, they must have necessarily assumed that the tissues of which the intima is composed are capable of entering into tissue proliferation subsequent to the traumatism inflicted by the ligature. This doctrine was annihilated by Virchow, who taught that the intima does not respond to any amount of stimulation, and that, if the irritation is

[1] Experimentelle Untersuchungen über die Herkunft der Tuberkelelemente, Würzburg, 1875.

increased to a certain degree, necrosis of the intima takes place as a constant and unavoidable result.

For a long time it was claimed that the intima takes no active part either in the organization of the thrombus, or the process of cicatrization. The advancement made in histology and the experimental investigations which have characterized the history of medicine for the last forty years, have thrown new light upon the subject. The important part taken by stable tissue cells in all regenerative and pathological changes is again fully realized by the most competent observers, and the presence of inflammatory changes in the intima after ligature is now fully established.

His[1] pointed out the difference between epithelia and endothelia, and showed that the latter originate exclusively from the mesoblast, belonging, therefore, to the series of connective-tissue formations possessed, like all analogous structures, of the common property of being capable of entering into tissue proliferation. As early as 1824, Rokitansky taught that primary union of the vessel-walls and definitive obliteration could take place independently of the formation of a thrombus. He believed that the surfaces of the intima adhere nearest to the ligature, and that the process of obliteration proceeds from this point to where collateral circulation is established. The vessel is obliterated as it has no further physiological function to perform. He was never able to discover any vessels in the thrombus.

Cohn[2] was the first to assert that obliteration of a vessel after ligation is due to proliferation of the endothelial lining of the intima. Lancereux in France and Förster in Germany adopted his views.

Waldeyer, who is a firm believer in the endothelial origin of the intra-vascular cicatrix, describes the process of organization of the clot after ligature as follows: "The intima is rendered vascular from the media. From the intima loops of capillary vessels project into the thrombus accompanied by an envelope of delicate spindle-shaped cells from the endothelial lining, which constitute the basis of the future connective tissue."[3]

[1] Die Häute und Höhlen des Körpers, Basel, 1866.

[2] Klinik der embolischen Gefässkrankheiten, Berlin, 1860.

[3] Zur pathologischen Anatomie der Wundkrankheiten, Virchow's Arch. vol. xi. p. 379.

Thiersch[1] has studied experimentally the process of obliteration in small vessels in wounds of the tongue of the guinea pig. At the point of injury, both in arteries and veins, he has witnessed the rapid production of endothelial cells to which he attributes the most important function in the organization of the clot and the obliteration of the vessel.

Czerny[2] claims that organization of the clot is complete five days after ligation. Although he refers this process to the presence of white corpuscles which accumulate in the thrombus and the vessel-walls, he satisfied himself that the endothelia at and near the seat of the ligature multiply with great rapidity.

Baumgarten[3] has made some very interesting experiments to establish the capacity of the endothelia for proliferation. He asserts that obliteration of a vessel takes place without the intervention of a thrombus, as when the column of blood is excluded between two ligatures. He operated on rabbits by applying a double ligature, either excluding the blood in the intermediate portion of the vessel, or leaving it between the ligatures. In both instances he obtained prompt obliteration of the vessel.

In case the blood was excluded from the vessel, he observed a cellular product in the lumen of the vessel a few days after operation; these cells he believed to be the product of endothelial tissue proliferation, which was most marked in the immediate vicinity of the ligatures. The modified endothelia are converted into fibroblasts (Neumann) and spindles of connective-tissue cells. When a thrombus was present, the granulation tissue gradually displaced the thrombus, and was finally converted into vascular connective tissue. The vascularization always took place by vessels from the vasa vasorum. The ligatures were tied with sufficient force to divide the two internal coats. By applying an irritant to the outer surface of veins, he also noticed after twenty-four to forty-eight hours proliferation from the endothelial lining of the intima. The endothelia enlarged and assumed a cuboidal shape, showing conclusively that

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[1] Ueber den Verschluss der Gefässe bei Acupressur, Centralbl. f. d. med. Wissensch., 1868, No. 50.

[2] Von Pitha u. Billroth's Handbuch der Chirurgie, vol. i. part ii.

[3] Ueber die sogenannte Organisation des Thrombus, Centralbl. f. d. med. Wiss., 1876, No. 34.

they participated in the inflammatory process which affected the entire thickness of the vein-walls.

For one of the most valuable contributions to our knowledge of cicatrization in blood-vessels after ligature we are indebted to Fritz Raab.[1] His experiments were made on dogs, and always under antiseptic precautions. The sheath of the vessel was opened at two places from 1 to 4 cm. apart, and after first tying the proximal ligature in the case of arteries, and the distal ligature in the case of veins, the blood was squeezed out of the vessel before tying the second ligature, securing thus a bloodless space between them. He cautioned against opening the sheath extensively for fear of producing necrosis in the intermediate section of the vessel. As ligature material, silk was used, which was always cut short. If the ligature cut through or the wound did not heal promptly, a funnel-shaped sinus remained which led to the ligature, and in all of these cases the portion of the vessel-walls towards the wound was found destroyed.

Experiment 1. Carotid artery; intermediate portion of vessel between ligatures 2 cm. Animal killed after twelve days. At seat of ligature, artery, vein, and vagus blended in a spindle-shaped, indurated mass of connective tissue. Vessel between ligatures completely obliterated. Adventitia slightly infiltrated with cells. Media and intima normal. Endothelial lining changed into several layers of oblong spindle-shaped cells. Where surfaces of intima were brought into apposition the lumen was found obliterated. Remnants of blood-cells were also found which had remained in contact with inner walls of vessel. No vessels in the endothelial layers except at the seat of ligatures, where intima and media had been circularly divided. Silk ligatures not infiltrated with cells. Under ligatures, fibres of adventitia remained intact. Proximal coagulum 2 cm. in length, between folds of intima new endothelial formations.

Experiment 2. External jugular vein; ligatures 4 cm. apart. Animal killed on twelfth day. Around vein some induration. On distal side, thickening of vein-walls; lumen smaller, containing a brittle red-brown coagulum. Between ligatures, and two inches on proximal side, the vessel was transformed into a fibrous cord. Between ligatures all coats of vessels changed. Endothelia multiplied and converted into spindle-shaped cells; between them embryonal connective-tissue cells and round cells. No vessels except close to ligatures, where vessels from vasa vasorum had penetrated the interior of the vein.

In commenting on these cases he gives his views concerning the

[1] Ueber die Entwickelung der Narbe im Blutgefäss nach der Unterbindung.

formation of the intra-vascular cicatrix. Slight irritations will produce remarkable morphological changes in the endothelial cells. The walls of the veins do not require a great amount of traumatism to produce these results. During the first forty-eight hours after ligation, marked changes are observed, which gradually extend from points of ligature to a certain distance, and it is immaterial whether the vessel contains blood or whether it has been rendered bloodless between the ligatures.

The first change in the endothelia consists in an enlargement of the nuclei, which imparts to the intima an increased wavy appearance. Later, the nuclei enlarge towards the periphery of the cells, displaying the protoplasm so that the protoplasmic spaces are diminished. The cells at this time assume a polyhedric or rounded contour. The naked eye now detects a loss of the glossy surface of the intima. Similar changes can be observed in the endothelial lining of small arteries and veins in inflamed tissue. The sharp contour of the nuclei is lost as soon as the cells have attained a certain size. The protoplasm is interspersed with fine molecules which aggregate at three or four points, and the cell soon contains from three to four nuclei.

Other smaller pyriform or spindle-shaped cells are found in immediate contact with the large cell. These new cells originate from nuclei, and leave the cell-wall by the budding process. These small or daughter-cells are found in the lumen of the vessel on the surface of the endothelial layer. They become flattened, and eventually assume the shape of the old cells. They are variable in shape, according to the stage of development and locality in which they are found. In the folds of the intima they are flat, spindle-shaped, and elongated; on the surface, towards the lumen of the vessel, round or polyhedral. The proliferation takes place in the bloodless space as rapidly as when a thrombus is present. The obliterating process is completed earliest near the ligatures. In veins the round cells are most numerous, while in the arteries the flat spindle-shaped cells predominate. As the connective-tissue is in closer proximity to the endothelial cells in veins than in arteries, the proliferating process cannot be observed so satisfactorily as in the latter vessels. For the same reason the proliferation of endothelia begins later in arteries, and the process is accomplished less rapidly. At first the proliferation is witnessed in the folds of the

intima in the shape of spindle-shaped cells which fill the spaces between the elevations, forming bridges from one fold to another.

While in the normal intima the endothelial lining consists of two or more layers of cells, in the inflamed intima an amorphous mass is found which is interspersed with cells of high refractive power. These new cells accumulate in great numbers, and finally perforate the endothelial lining into the lumen of the vessel. Heubner found the same conditions in examining specimens of endarteritis in vessels of the brain. In contradistinction to Heubner, Raab considers the cells on the surface of the endothelia as new productions. The nutritive supply for the endothelia is not derived from the blood circulating in the vessels, but is derived from the vasa vasorum of the adventitia.

The cement substance liquefies and gradually disappears during active proliferation. If the inner surfaces of a vein or artery are kept in mutual contact, primary union takes place at once by means of long spindle-shaped cells which are the product of the endothelial cells. The space between the surfaces of the intima occupied by these cells is finally completely obliterated and the inner coat is transformed into one tissue. If a thrombus is present the embryonal cells of the intima send prolongations into the thrombus, which unite with similar projections of other cells, thus forming a complete network of protoplasmic strings permeating the entire coagulum. Upon these strings new nuclei appear, which are the product of an aggregation of molecules. The connecting strings between the nuclei become narrower and eventually disappear, setting free the nuclei as new tissue elements.

Some of the large spindle-shaped cells divide into two or more cells. The spindle-shaped cells arrange themselves into bundles with spaces between them which contain blood-corpuscles; these spaces may easily be mistaken for new blood-vessels. The endothelial product is not supplied with vessels until the tunics participate in the process, when vascularization takes place from the vasa vasorum. Obliteration can take place by tissue derived exclusively from the intima, but all coats of the vessel assist in the process from the beginning. The connective tissue immediately beneath the swollen endothelial cells is rendered loose and succulent, the spaces between the individual bundles are widened, and an occasional cell is seen in them. Towards the periphery of the vessel the spaces

between the elastic tissue fibres are widened and active infiltration of cells is also witnessed here.

These cells, like the endothelia, send out projections in the form of long strings of protoplasm, forming networks with the connective-tissue interspaces. The connective-tissue between elastic fibres proliferates. The connective and elastic tissue spaces are populated with cells of various shapes and sizes. We find here cells in all stages of division, large, round, polygonal, and pyriform-shaped, containing in their interior from two to four smaller cells. Around the vessels of the adventitia round lymphoid cells appear which infiltrate all the tissues of the vessel. The microscopical appearances resemble in many respects the picture presented by the inflamed tissue in the cornea or cartilage.

Finally the new tissues perforate the endothelial layers and enter the lumen of the vessel, and mingle with the products of the endothelial cells, forming a common cicatricial tissue while the elements are being converted into connective tissue. Vessels of the adventitia enter through the coats of the vessel into its lumen, but the principal vascular supply of the intra-vascular tissues is derived from vessels which enter near the ligature through the spaces made by the circular division of the inner coats by the ligature. The ligature not only produces circular division of the inner coats, but also longitudinal lacerations of the intima. The extent and degree of laceration of the walls of the vessel are in direct proportion to the amount of granulation tissue which is formed subsequently.

Under the most favorable circumstances direct union of the inner surface of the intima takes place exclusively by endothelial proliferation without a granulative thrombus. Where this result is not obtained the granulation tissue is formed first, and advances from the seat of ligature towards and into the lumen of the vessel, where it unites with the endothelial product and produces the tissue which has heretofore been known as the organized thrombus. The granulation tissue is composed at first of cells, later of cells, fibres and vessels, and finally the number of cells is diminished and the connective tissue is increased, when the vessel is reduced in size and is ultimately converted into a string of connective tissue.

Riedel[1] studied the process of cicatrization in blood-vessels

[1] Die Entwickelung der Narbe im Blutgefäss nach der Unterbindung, Deutsche Zeitschrift für Chirurgie, vol. vi. p. 450.

experimentally in the same manner as the preceding author, and arrived at similar conclusions. He used catgut in place of silk, and dogs and rabbits were made the subjects of his experiments. The space between the ligatures was made bloodless by isolating the vessel, raising it from its bed, and placing a spatula underneath. In two of the specimens the interior of the intervening portion of the vessel was found obliterated. One specimen was obtained nine days, and the other sixty-three days after ligation. In the first specimen the endothelial proliferation appeared in the shape of spindle-shaped connective-tissue cells which filled only two-thirds of the lumen of the vessel. In the second specimen the connective tissue in the interior of the vessel was distinctly fibrillated. The elastic layer of the intima had suffered in many places a loss of continuity to give passage to blood-vessels from the media into the thrombus.

In the next experiment two ligatures were applied 1 cm. apart, including a column of blood. The animal was killed on the ninth day. In place of the white blood-corpuscles in the red thrombus, large cells containing from one to three nuclei were found; the cell contents were either granular or round globules of a yellowish color. The identity of these globular masses with the red blood-corpuscles deprived of the greater part of their coloring matter was unmistakeable. Some of these large cells appeared shrunken, with irregular surfaces, denoting incipient disorganization. While these cells were found uniformly present throughout the intervening portion of the vessel, the endothelia, half way between the ligatures, remained unchanged. Nearer the ligatures the endothelial layer was much thickened, completely filling the longitudinal folds of the intima. On the surface of the thickened endothelial lining were thin flat cells, and behind these new endothelial cells were seen the embryonal connective-tissue cells arranged irregularly with a variable amount of intercellular or cement substance.

In other transverse sections, through portions of the vessel between the ligatures, delicate processes could be seen springing from the parietal proliferation of the endothelial layer, penetrating the thrombus, reaching into the interior of the vessel and uniting with similar processes from the opposite side. These processes carried with them a layer of endothelia. At a right angle with these processes could be seen similar structures, thus dividing the interior of the vessel into spaces lined with endothelia. As the ligatures

were approached these spaces grew smaller, containing in their interior well preserved red corpuscles and the large cells previously described. Any activity on the part of the blood-corpuscles in this process could be safely excluded, and cicatrization could be referred exclusively to the action of the endothelial cells.

The question presented itself: Would the same process take place in a thrombus not included between two ligatures? To furnish a satisfactory answer, a thrombus, twenty-seven days old, in the femoral artery of a dog was examined. The appearances presented were identical. The network of vessels in the thrombus communicated directly with the vessels of the media. Injections made into the lumen of the vessel sometimes followed processes from the lining of the vessel and filled the spaces in the thrombus. About the seat of the ligatures the external coats were actively engaged in aiding the processes of cicatrization.

The connective tissue proliferates, the new cells being directed in such manner that they point towards the lumen of the vessel. They approach the intima accompanied by blood-vessels, penetrate the *membrana fenestrata*, and unite directly with the endothelial formations. The spaces in the *membrana elastica* of the intima increase in size as the ligatures are approached, so that in place of circular necrotic pieces of tissue, large cicatrices are formed. Ligatures always produce necrosis of tissue underneath. A thrombus, twelve days old, showed the endothelial proliferation in the form of cells corresponding to the windings of the elastic intima. The membrane projected into the lumen of the artery. The conical end of the thrombus was also covered with endothelial cells.

It is a well-known fact that connective tissue can be transformed into endothelial cells, as has been repeatedly observed in the formation of new synovial sacs. A thrombus not included between ligatures receives its first vascular supply from the lumen of the vessel. When blood is included between two ligatures, a scanty network of vessels reaches the lumen of the vessel from without.

Uhle and Wagner[1] testify positively to the importance of the functions of the endothelial cells and connective tissue in intravascular cicatrization in the following language: "In all probability the most important structures in the process of organization are the

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[1] Handbuch der allgem. Pathologie. Leipzig, 1876.

endothelial cells and connective tissue of the intima. These proliferate within a few hours after ligation, and are first transformed into spindle-shaped cells, and later into connective tissue and vessels. As early as six or eight days after the formation of the thrombus, especially towards its periphery, it is traversed by a network of young capillary vessels which increase rapidly for the next few days. During this time the fibrin and blood-corpuscles disintegrate in the same manner as the so-called dissolution of the thrombus. The new vessels in the thrombus and intima enter into communication with the original and new vessels of the media and adventitia, and thus a genuine circulation is established throughout the entire thrombus; later an anastomosis is formed between the vessels in the thrombus and the lumen of the vessels. Reparative changes are initiated at first in the immediate vicinity of the ligature. After four to six weeks the circulation in the thrombus is completed, when the vessels again gradually disappear, the cement substance grows firmer, the red blood-corpuscles and fibrin, which still may remain are absorbed. At last only a minute connective-tissue string remains, which can only be recognized by the aid of a microscope."

Cornil and Ranvier[1] have carefully investigated the part taken by the endothelia in cicatrization within blood-vessels after ligature. The following is a summary of their observations: Within twenty-four hours after ligation a clot forms in the central end, which reaches to the nearest collateral branch. At this time the endothelia are swollen and granular, containing a round nucleus and frequently several nuclei. On the following day the thickening of the intima is well marked, especially near the ligature. The thickening of the internal coat is due to a proliferation of cells which appear spindle-shaped, but in truth are flat. They resemble endothelia or cells of connective tissue swollen by inflammation. On the eighth day the internal coat puts forth nipple-shaped elevations, which are particularly well marked at the point of ligation. By the twelfth to the fifteenth day these elevations on the cardiac side of the ligature penetrate into the blood clot, accompanied by capillary blood-vessels which run parallel to the axis of the elevations.

In longitudinal sections it is seen that, at the point of implantation of these projections, the middle coat of the artery has

[1] A Manual of Histology, by Shakespeare and Simes. Philadelphia, 1880.

disappeared, so that they appear to spring from the external coat. Their vessels are derived from the vasa vasorum. The clot disappears before the new tissue, the spaces between them being occupied by discolored red blood-corpuscles, granules, and a few white corpuscles, an appearance which simulates blood-channels, as described by O. Weber.

I will mention a few recent American authors who assign to the endothelia an important, if not essential function in the formation of the intra-vascular cicatrix.

Shakespeare[1] has made a number of experiments to determine what histological elements are active in the obliteration of vessels after ligation, and his views are summarized in the following: An acute endarteritis follows ligation, during which the endothelia and other cellular elements of the intima multiply with great rapidity. The inflammatory changes are most marked near the ligature. The new cells are usually flattened and more or less endothelial in appearance. Among these large endothelioid cells are a considerable number of lymphoid cells and a few red blood-corpuscles. The cement substance holding these elements together, is sometimes structureless, sometimes granular, and occasionally slightly fibrillar.

In a few days the walls of the plastic clot begin to bud and put forth granulations which encroach upon the space between the inner surface of the vessel and the blood clot, and upon the blood clot itself. The granulations remove the clot by pressure and absorption. The granulations have much the same structure as granulation tissue in any other part of the body. They are covered by a layer of endothelial cells. The base of the granulations rests upon the elastic lamina of the intima which, up to the twentieth or twenty-fifth day, remains unchanged, forming a sharp boundary between the middle coat of the artery and the proliferation of the intima. There is usually no indication of its perforation by a capillary loop from the vasa vasorum. As the projections of granular tissue approach each other, sinuses are formed in which the blood circulates and supplies capillary vessels which at this time are formed at the bottom of the plastic clot. At the same time capillary varices form in the embryonal tissue of the outer coats of the vessel in the neighborhood and at the location of the ligature. They receive their

[1] Cornil and Ranvier's Manual of Histology, p. 322.

blood from the vasa vasorum. In a few days the two capillary systems form a communication with one another by means of connecting loops which perforate the space between the injured elastic membrane of the intima at the point of ligature. The granulation tissue undergoes cicatrization and contraction, which obliterate the vessel.

The author describes at some length the laminated structure of the thrombus, and it is evident that the vascular networks in the thrombus were simply spaces between the lamina, which were occupied by the pre-existing blood-corpuscles in the thrombus, and that vascularization took place exclusively from the vasa vasorum.

Agnew[1] believes that the production of the new tissue may be accomplished by white blood-corpuscles, endothelia and migrating corpuscles.

Lidell[2] holds that the thrombus undergoes organization, but attributes the definitive closure to adhesive inflammation of the inner and middle coats, the plastic exudation from the adventitia giving additional strength to the walls of the vessel. In speaking of the same process in veins he says: "Again, veins may, and often do, undergo repair after ligature without any inflammation whatever, whether adhesive or otherwise, as Mr. Travers was the first to show."

Wyeth[3] takes a more advanced ground and regards the endothelia as the essential element in effecting definitive obliteration. He writes: "The permanent occlusion is due to new-formed tissue springing from the normal cells of the intima."

Heitzmann says: "Occlusion of ligated vessels is due mainly to endothelial proliferation, and vascularization of the thrombus starts in the inflamed intima."[4]

The fact that endothelia are endowed with sufficient vitality to proliferate new tissue is, however, not based alone on the observations of practical surgeons and experimental research, it is also supported by pathological processes which affect the inner tunics of the vessel. Virchow, in his experiments on embolism, introduced triangular pieces of rubber into the right heart through the external jugular vein. After four weeks he found the piece of rubber

[1] The Principles and Practice of Surgery, vol. i, p. 155.

[2] Injuries of Blood-vessels, Internat. Encyclop. of Surgery, 1883, vol. iii.

[3] Surgical Diseases of the Vascular System, Internat. Encyclop. of Surgery, vol. iii, p. 351.

[4] Micros. Morphol. of the Animal Body in Health and Disease, N. Y. 1883.

impacted in a branch of the pulmonary artery, encysted in a vascular capsule composed of spindle-cells and flat-cells, evidently products of the endothelial lining.

The inflammatory changes which occur in the endothelia of serous membranes have been studied by Rindfleisch, Klein, and Cornil and Ranvier. Kundrat selected for his investigations the peritoneum, Chapman the pericardium, and Albert the synovial membranes. Ponfick has called special attention to the rapid changes which take place in the endothelia during the acute stage of infectious diseases, and Heubner has assigned to them a special susceptibility for the syphilitic virus.

Although O. Weber[1] takes it for granted that thrombosis and organization of the clot are the two essential conditions which precede and accompany the definitive obliteration of a vessel, he states distinctly that he has seen the endothelia repeatedly in a condition of so-called cloudy swelling, which would indicate that he has witnessed the first stage of progressive tissue metamorphosis in these structures—the first stage of inflammation.

Friedländer[2] has described a heretofore unknown affection of the arterial coats which he has called "arteritis obliterans." The affection is located in the intima of arteries of medium and smallest calibre, and results in stenosis and sometimes complete obliteration of the vessel. The process is inaugurated by the appearance of numerous round-cells between the innermost lamellæ of the elastic layer and the endothelial lining. The cells increase in size, intercellular substance is formed, and the new product presents all the characteristic appearances of granulation tissue with an abundant supply of new vessels, some of which are of considerable size. The proliferation may be limited to small points, or it may involve the entire circumference of the vessel. The new-formed tissue is generally converted into dense connective tissue, seldom undergoing fatty or calcareous degeneration.

A physiological process very similar to the one described takes place during the occlusion of the *ductus arteriosus Botali* in the vessels of the umbilical cord after birth, and in the arteries and veins of the uterus after parturition. Analogous changes are observed in

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[1] V. Pitha u. Billroth's Handb. d. allg. u. spec. Chir. vol. ii. div. ii. part i.

[2] Ueber Arteritis obliterans. Centralblatt f. d. med. Wiss. No. 4, 1876.

the small vessels in tissues which are the seat of chronic inflammation. Heubner has described it as it occurs in the vessels of the brain, but he was wrong in asserting that it was caused by the specific effect of the syphilitic virus.

Regarding the source of the cellular elements, he mentions three probabilities: 1. Either they are the product of the endothelia of the intima; 2. They originate from white blood-corpuscles in the lumen of the vessel which must pass through the endothelial lining of the vessel; 3. Or leucocytes from the vasa vasorum. Friedländer is inclined to the belief that they are derived from all three of these sources.

Winiwarter[1] reports a case of spontaneous gangrene of the foot in a man fifty-seven years of age, who presented no symptoms of atheromatous degeneration of the vessels. On submitting the vessels of the amputated member to a thorough microscopical examination, he found a proliferation of endothelial cells of the intima in the arteries and veins, which had produced narrowing, and, in some places, complete obliteration of their lumen. He found the proliferation most active in small vessels which are composed exclusively of endothelia. The endothelia increase in size and assume a cuboidal shape, and as the proliferation advances the endothelial lining is thickened by additional closely packed layers of cells.

In examining transverse sections of the smallest arteries, he observed the following appearances: The endothelial cells are arranged in concentric layers; towards the lumen of the vessel they are spindle-shaped and partly converted into connective tissue. In places where the vessel is not entirely obliterated, its lumen often appears irregular in outline, owing to the greater activity of tissue production in some portions of the inner walls of the vessel than in others. The media is also thickened, partly by the increase of muscular fibres, and partly by cell infiltration from the intima. The cellular thrombus in the interior of the vessel is organized, and the cellular elements are gradually converted into connective tissue which completely and permanently obliterates the vessel, transforming it into a round string of connective tissue. In the interior of such strings, deposits of a homogeneous substance may be seen, which

[1] Ueber eine eigenthümliche Form von Endarteritis und Endophlebitis. Archiv. f. klinische Chirurgie, vol. xxiii. p. 206.

indicate that retrograde metamorphosis of the cellular elements has occurred in place of organization into connective tissue. The same conditions were also found in veins.

Baumgarten[1] has found the vasa vasorum included in the ligature in ligating large vessels, a favorable locality to study this process. The inflammatory process begins in the adventitial structures, and extends by continuity to the endothelial lining, where proliferation takes place promptly and with considerable activity. Giant-cells may originate from endothelia, and, in case of very minute vessels, a single cell may block the calibre of the vessel completely. The endothelial cells, in the course of time, are changed into spindle cells, and finally into connective tissue. The round cells found in the media and adventitia undergo the same transformation.

Cornil and Ranvier[2] have seen several times cases of acute circumscribed endarteritis in the form of patches as an isolated lesion. Multiplication of the endothelia on the surface of the internal coat is peculiar to acute endarteritis, while in the endarteritis preceding atheromatous degeneration, the proliferation takes place in the deepest layer of the intima. Multiplication of cells takes place by division of nuclei. A careful study of the new elements demonstrates that they spring from the intima. Peri-arteritis always coexists. The external coat produces granulation tissue. In the middle coat proliferating elongated cells of smooth muscle are seen, while the elastic fibres are broken down and absorbed.

As a last witness we will hear Heitzmann[3] concerning the endothelia when subjected to irritation and in a condition of inflammation, without alluding to the peculiar views on protoplasm entertained by this author. Endothelia, being formations of living matter, are susceptible of undergoing rapid changes under the influence of irritation. The process is always secondary to affections of the subjacent vascular connective tissue. The inflammatory changes in this tissue as in every other, consist in an increase of tissue. The endothelial cells in the initial stage become coarsely granular, or assume the "condition of cloudy swelling." The coarse granules increase in size, and constitute the inflammatory elements in

[1] Ueber chronische Arteritis u. Endarteritis, Archiv f. path. Anatomie u. Phys., vol. lxxiii. p. 90.

[2] A Manual of Histology, by Shakespeare and Simes, Phila. 1880, p. 307.

[3] Loc. cit.

all stages of development, reaching the highest development in the nucleated cells.

The endogenous new formation of elements within the epithelia was first maintained by Remak in physiological, and afterward by Buhl, Rindfleisch, and others in pathological conditions, and its existence thoroughly proved by L. Oser. In opposition to the supposition that the corpuscles visible in the endothelia had immigrated from without, Oser demonstrated the origin of inflammatory corpuscles *within* the epithelia. Heitzmann corroborates this view.

A sufficient number of competent and reliable authorities have been cited, and enough has been said to prove that the vascular endothelia, when subjected to a sufficient degree of irritation, are susceptible of assuming inflammatory changes, and capable of proliferating new tissue elements which, if not the only reparative material, at least render essential assistance in the process of cicatrization after ligature. It is important, however, to remember that the process of endothelial proliferation is secondary to the inflammatory changes which take place in the vascular connective tissue. The peri-arteritis and meso-arteritis which immediately follow ligation are attended by the formation of new blood-vessels which penetrate the intima, bringing the endothelial lining in direct contact with the circulation, which places the endothelia under the same conditions of nutrition and subject to the same pathological processes as any other vascular organs.

XX. Formation of Cicatrix from Connective Tissue.

The formation of the intra-vascular cicatrix from connective tissue has been frequently mentioned as the cause of the definitive closure of vessels since the introduction of the circular ligature by Jones. It was urged that the division of the two inner coats by the ligature and the curling inward of the lacerated tissues towards the lumen of the vessel would not only allow of the adventitia being brought in contact, but would also create a wound surface which would heal in the same manner as wounds in any other locality.

The important function performed by the connective tissue in repairing solutions of continuity in any part or organ is well established and recognized by all authorities. The connective tissue is more widely diffused throughout the entire body, and its susceptibility to undergo embryonal changes in a remarkably short time is

as well known as its capacity to produce various types of tissue. It is the tissue which is invariably present in all cicatricial formations. This tissue is present in all coats of the arteries and veins, it accompanies blood-vessels wherever they go, hence it is only reasonable to assume that it plays an important part in the reparative process in vessels after ligation.

Kölliker and Eberth claimed that the connective tissue between the endothelial lining and the elastic layer of the intima proliferates and renders material assistance in the permanent closure of vessels.

Durante believed that when only one ligature is applied, obliteration of the vessel takes place by proliferation of the intima; when the double ligature is used, the media and adventitia assume this office.

Reinhardt, after declaring that the thrombus remains passive after ligature, asserts that obliteration of the vessel takes place by an exudation or blastema from the adventitia.

Auerbach,[1] under Köster's directions, studied the obliteration of vessels experimentally on dogs and rabbits after single and double ligation. In using the double ligature he compared the results obtained by excluding the column of blood in the intervening vessel with those cases where blood was included between the ligatures. He ascertained that those vessels furnished the most favorable conditions for obliteration where the intervening portion was moderately filled with blood.

The first change observed in the coats of the vessel after ligation was an inflammatory infiltration in the adventitia, proceeding in a central direction toward the lumen of the vessel. The acute stage was followed by a chronic granulation process which was established almost exclusively in the adventitia and intima. The inflammatory infiltration appeared earliest at the seat of the ligature and reached at this point the highest degree of development. The intima was supplied with vessels from the adventitia. The definitive obliteration of the vessel was due entirely to connective-tissue proliferation from the intima. The endothelia, although they manifested an attempt at progressive metamorphosis, did not produce new tissue. In case the adventitia was injured or removed prior to operation no changes occurred in the two inner coats.

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[1] Ueber die Obliteration der Arterien nach Ligatur. Dissertation, Bonn, 1877. Virchow u. Hirsch's Jahresb. 1878, vol. i. p. 233.

Roser[1] asserts that obliteration of an artery often takes place without a thrombus, and that the essential structure in this process is the adventitia. After the two internal coats have been severed by the ligature, the external coat is brought in contact, and union takes place in the same manner as in other wounds. As a frequent cause of secondary hæmorrhage he mentions that small traumatic aneurisms sometimes form at the seat of ligature in the sac of the adventitia, which rupture, and that in case of ligation of the artery in its continuity, the tension exerted by the vessel increases the danger of rupture. In healthy animals occlusion of an artery takes place in a satisfactory manner even if it is tied in the immediate vicinity of a large branch. The same can be said of arteries which are ligated after amputations. Only in exceptional cases does obliteration take place through the medium of a thrombus.

For the most thorough investigations respecting the definitive closure of vessels after ligation from connective-tissue proliferation, we are indebted to Tschausoff.[2] His experiments were made on dogs. The specimens for microscopic examination were hardened in Mueller's fluid for two or three weeks and subsequently immersed for two to three days in absolute alcohol, and finally a few days in turpentine, and for the purpose of making sections, they were incorporated in a cylinder composed of wax and stearin.

He carefully traced the tissue changes in specimens from one to one hundred and twenty days old. In specimens three days old he noticed an increase in the size and number of the vessels in the external coat. At this time the connective tissue of the intima had undergone considerable development, the fibres being directed transversely to the lumen of the vessel and in immediate contact with the endothelial lining. In a thrombus of the brachial artery obtained eight days after ligation he found in transverse sections, the vessels of the media, adventitia, and, to a lesser extent, of the intima, stained blue from colored injections. The new connective-tissue formation of the media and intima had gained entrance at some point into the lumen of the vessel, reaching as far as the center of the thrombus at certain places. In a specimen of the brachial artery

[1] Zur Theorie der Blutstillung u. d. Nachblutungen. Archiv. f. klinische Chirurgie, vol. xii. p. 223.

[2] Ueber den Thrombus nach der Ligatur. Arch. f. klin. Chirurg.

nine days old, the lumen of the vessel near the ligature was found completely filled with new connective tissue.

In a specimen of the femoral artery eighteen days old all the tissues of the vessels showed a beautiful network of capillary vessels which were derived from the external coat. The original structures of the intima and media were at many points obscured by the new formative tissue. The endothelial layer in some places was preserved, at some points indistinct, and at others completely obscured. The lumen was filled with a compact mass of organized tissue. In a thrombus of the brachial artery twenty days old the proliferation of connective tissue was seen to project beyond the endothelial lining of the intima. In a thrombus of the brachial artery twenty-five days old the endothelial lining was seen to be almost completely covered by new tissue in some places, while at others it was either indistinctly visible or somewhat thickened. The new connective-tissue fibres in the intima and media were disposed transversely, obliquely, and longitudinally. The lumen of the vessel was completely closed by new connective tissue, the most recent formation corresponding to the center of the vessel, while vascularization increased in a peripheral direction.

In a specimen of the carotid artery thirty-two days old all tissues of the vessel-walls were stained by the injection fluid. The endothelial layer was covered partly or completely with organized exudation material; near the ligature the endothelial cells had completely disappeared, and the fibres of the intima and media could no longer be seen. The lumen of the vessel was completely obliterated. The remains of the thrombus consisted of pigment granules. In a specimen of the femoral artery forty days old only the external coat was discernible. The endothelial layer was expanded, infiltrating the intima.. In a specimen of the femoral artery fifty days old the endothelial layer was obscured by new connective-tissue fibres; the lumen near the ligature was obliterated.

In a specimen of the carotid artery sixty days old the endothelial layer was found mostly covered with embryonal connective tissue, and at some points somewhat thickened. In a preparation of the femoral artery, obtained one hundred and twenty days after operation, the lumen occupied by a thrombus was not obliterated, but near the ligature the vessel was completely closed. The vessels in the walls of the artery were reduced in size and number. The

endothelial layer in some places was displaced by new tissue, at other points it could be distinctly seen. The young connective tissue in the lumen of the vessel was defined by the plicated endothelial layer, and adhered all around to the inner walls of the vessel. No vessels could be seen in the intra-vascular cicatrix.

In commenting on these specimens, Raab alludes to the constancy with which inflammatory exudation takes place at the seat of the operation and ligature. The thrombus varies in size, and frequently does not reach as far as the nearest collateral branch. As a rule, the central is larger than the peripheral thrombus. Three to four weeks after ligature adhesion of the inner walls of the vessel takes place near the ligature by connective-tissue proliferation. The blood-corpuscles in the thrombus become granular, disintegrate, and are absorbed. Dissolution of the thrombus commences where organization of new tissue begins, that is, near the ligature and in the peripheral portion of the clot.

That the pre-existing tissues in the coats of the artery are active in the process of obliteration is made evident from the fact that the walls of the vessel are invariably very much thickened. Tissue proliferation in the coats of the vessel could be observed in cases where no progressive changes could be recognized in the thrombus. No attempt at organization ever took place prior to the fourth day. Vascularization of the inner tunics is attended by an active connective-tissue proliferation; the new tissue advances in a central direction and finally gains entrance into the lumen of the vessel.

The best possible proof of the importance of the vessel-walls in the process of obliteration is furnished by the fact that tissue proliferation takes place within them, independently of the formation of a thrombus. The connective tissue, wherever found in the tunics of the vessel, takes part in the process, the endothelia and muscular fibres of the media taking no active part. The endothelial layer is perforated by the new connective tissue, or is pushed before it towards the center of the lumen of the vessel. The final disposition of the endothelia and muscular fibres probably consists in atrophy and absorption.

With the evidence before us we are certainly not warranted in assuming with Tschausoff that the endothelia are not susceptible of tissue proliferation under such conditions as are created by the ligature. Endothelia and connective tissue have one common, embryonal

origin, and their relations are such that in the vessel-walls, changes in one are very apt to extend to the other. Connective tissue can be transformed into endothelia, and there is no well-founded reason why the reverse should not occur. Even Tschausoff, who explains the whole process of cicatrization from a standpoint that the connective tissue is the only active element, volunteers the assertion that on several occasions he has seen the endothelial lining thickened, which certainly would imply tissue increase from pre-existing cell elements.

After having excluded fibrin and the morphological elements of the blood within and without the walls of the vessels, as active agents in accomplishing definitive obliteration of the vessel after ligature, we are prepared to impute to the endothelial cells, and to the connective tissue in the vessel-walls, the rôle of active agents in the formation of the intra-vascular cicatrix. Both of these histological elements are transformed into embryonal tissue, which in turn is changed into mature connective tissue. The tissue proliferation is. initiated at the point of greatest irritation, the seat of traumatism, and in the vascular adventitia; from these points it extends towards and into the lumen of the vessel.

This process of tissue proliferation is attended by the formation of new vessels from the vasa vasorum, which permeate all tunics of the vessel and supply the intra-vascular thrombus of embryonal tissue, which is finally converted into perfect connective tissue, and results in the definitive closure of the vessel. After the function of the vessel has been permanently abolished, all remaining histological elements from non-use and cicatricial compression undergo atrophy and eventually disappear completely by absorption, leaving only a string of connective tissue to indicate the extent of the obliterated vessel. The vessels in the cicatrix, having accomplished the purpose for which they were intended, gradually disappear, an occurrence which is followed by contraction and atrophy of the cicatrix itself.

XXI. Primary Union in Blood-Vessels after Ligature.

By the healing of a wound by primary union we understand rapid repair without suppuration. Used in this sense the term could be appropriately applied to almost every case of ligation of vessels, if the operation were done under antiseptic precautions. As

applied to vessels after ligature, this term, however, conveys another and still more significant meaning: it implies union between the inner surfaces of the lumen of an artery or vein, independently of the formation of a thrombus. The importance of guarding against suppuration, and of securing primary union of the wound, have been repeatedly alluded to as conditions which favorably influence the process of cicatrization in vessels. All conditions which impair normal healthy tissue proliferation at the seat of ligature affect unfavorably the reparative process after ligature. Atheroma of the tunics of the vessel, excessive inflammation and suppuration, cannot fail to exert a deleterious influence upon the reparative process in the walls of the vessel after ligature.

From what we have gleaned from the literature on thrombosis, tissue proliferation, and regeneration, we are justified in asserting that obliteration of a vessel after ligature takes place promptly without a thrombus, and further that the only function of the thrombus is to furnish a favorable soil for the development and maturation of the tissue which grows into the lumen of the vessel from the stable cells of its tunics, and which is destined to furnish the cicatricial tissue for permanent obliteration. Experiment and clinical observation furnish abundant evidence that closure of vessels frequently does take place without thrombus formation. The many cases of successful lateral ligation of large veins with preservation of the lumen of the vessel also speak in favor of primary union. H. Braun[1] collected fifteen cases of lateral ligature of veins, of which number, ten proved successful.

Eliminating the thrombus as an active agent in the obliterating process, we can say that union between the tissues which are brought in contact by the ligature takes place by tissue proliferation from the walls of the vessel itself. In its true sense direct or primary union never takes place, as in all instances closure is effected by granulation and cicatrization. In case the inner tunics are severed by the ligature, the lacerated surfaces are brought in contact with the adventitia, and repair takes place as in other tissues which are largely composed of connective tissue, the process extending from both sides of the ligature, where endothelia assist in the process of cicatrization. If, on the other hand, the continuity of the vessel is

[1] Verhandlungen der Deutschen Gesellsch. für Chirurgie, 1882.

not destroyed by the ligature, and the intima is brought in contact, the connective-tissue proliferation perforates the endothelial lining, and the elements of the latter join in the reparative process by being converted into embryonal and subsequently into connective tissue. The first inflammatory changes in endothelia are observed near the seat of the ligature about the third day, and the use of the temporary ligature has demonstrated that in arteries about the size of the radial, even when the internal coats are ruptured, three or four days are necessary for sufficiently firm adhesions to take place to resist the intra-arterial pressure.

While vascular tissues may unite firmly after twenty-four to forty-eight hours, as in wounds about the face and scalp, it requires from four to twelve days for the tissues of the vessel-walls to unite with the same degree of firmness. In the inner tunics of the vessels vascularization from the vasa vasorum must take place before tissue proliferation can advance to the requisite extent.

In conclusion, we can say that wounds in blood-vessels invariably heal by granulation and cicatrization, and that when a ligature is applied the definitive intra-vascular cicatrix is formed in a similar manner.

XXII. Experiments.

After many trials the sheep was selected as the subject of most of the experiments, as it was found that this animal presented the most favorable conditions for these operations. All operations were done under antiseptic precautions as far as circumstances would permit. The surface was shaved, thoroughly cleansed, and disinfected with a five per cent. solution of carbolic acid. Irrigation with a three per cent. solution was used occasionally during the operation, and always before closing the wound. The wounds were invariably completely closed with a continuous catgut suture, and hermetically sealed with salicylated cotton and iodoform collodium.

The vessel sheath was always opened to the extent of one inch or more, and the artery or vein completely isolated to the same distance, when two ligatures were placed underneath the vessel. The proximal end of arteries was tied first, and the distal end of veins. The vessel was made bloodless by placing the second ligature in close contact with the first and by making traction upon both ends, and sliding the loop to the required distance, when the return

of blood was prevented by an assistant compressing the vessel between the thumb and index finger until the ligature was tied. If any doubt remained as to the bloodless nature of the intervening space, these manipulations were repeated before tying the second ligature. In tying the ligatures it was the aim not to injure the internal coats, but simply to approximate the inner surfaces of the intima so as to effect provisional closure of the vessel. The ligatures were usually applied about half an inch to an inch apart. With the exception of the temporary, all ligatures were cut short. In removing the temporary ligatures the collodium dressing and suture were removed, and the vessel drawn towards the surface of the wound by making gentle traction on the ligature ends, when the loop of the ligature was carefully cut with small curved scissors. After the necessary examination the wound was irrigated, closed and dressed in the same manner as before. As an anæsthetic, ether, chloroform, or bromide of ethyl were used. The anæsthesia produced by the last was always of very short duration, while ether appeared to offer the greatest immunity against accidents.

The illustrations are of natural size, and represent the whole specimen as removed from the animal, and a cross section through the middle of the intervening portion. The two perpendicular lines at the extremities of the specimen show the location of the ligature, while the middle line denotes the place of the cross-section. I desire, in this place, to express my gratitude to my friend Dr. H. M. Brown, of Milwaukee, for the valuable aid rendered in preparing the illustrations for this article.

Double Ligation of Arteries.

Experiment 1. Right common carotid artery ligated with medium-sized catgut. Animal died from the effects of the anæsthetic six hours after operation. Proximal thrombus two inches in length; non-adherent. Minute distal thrombus in the folds of the intima. Inner coats of the vessel not injured by the ligatures. No appreciable changes in walls of vessel.

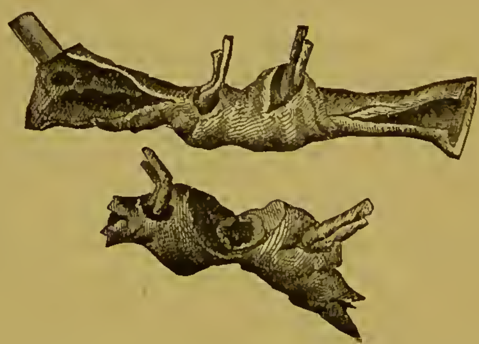
Experiment 2. Left common femoral artery ligated with coarse catgut, the distal ligature immediately above the profunda. Animal killed twenty-four hours after operation. Proximal thrombus, none. Minute distal thrombus. Loop of ligature covered by swollen adventitia. Lumen of profunda not closed by thrombus.

Experiment 3. Right common iliac artery ligated with braided silk. Distal ligature immediately above bifurcation. Animal killed three days after

operation. Proximal thrombus, none. Minute mural thrombus in external iliac artery. No thrombus in internal iliac artery. On removing proximal ligature vessel was found closed beneath it, while the intermediate portion of vessel remained pervious. Loop of ligature covered by granulation tissue.

Experiment 4. Right femoral artery tied with coarse catgut. Animal killed seven days after operation. Proximal thrombus extending to next collateral branch, three-fourths of an inch above the ligature; non-adherent, and only partly filling the lumen of vessel. Distal thrombus minute. Intervening portion of vessel filled with an adherent mass of granulation tissue. Ligatures softened and covered by granulation tissue. On removing central ligature, lumen of vessel was found to be completely and firmly obliterated by direct adhesion between the surfaces of the intima (Fig. 1).

FIG. 1.



Experiment 5. Right femoral artery ligated with medium-sized catgut; proximal ligature immediately below the profunda. Animal killed eight days after operation. Proximal thrombus about one inch in length, small, non-adherent, and not extending into the profunda, this vessel remaining pervious. Filiform peripheral thrombus. Intervening portion patent and adherent to surrounding tissues. Ligatures almost completely encysted; vessel under proximal ligature obliterated.

Experiment 6. Right femoral artery ligated with coarse braided silk. Animal killed ten days after operation. Small globular proximal thrombus. No peripheral thrombus. Intervening portion and ligatures inclosed by a fibrous capsule. Underneath distal ligature vessel walls adherent. Intervening portion on the side corresponding to the external surface covered by a thick layer of granulation tissue.

Experiment 7. Left common carotid artery ligated with silkwormgut ligature. Animal killed eleven days after operation. Proximal thrombus three inches in length; one circumscribed mural adhesion. Distal thrombus, none. Ligatures completely encysted in a spindle-shaped, fibrous capsule inclosing the intervening portion. Circular intravascular cicatrix underneath the peripheral ligature. Intervening portion patent. The inner tunics were not ruptured.

Experiment 8. Right carotid artery ligated with coarse catgut. Animal killed twelve days after operation. Ligatures and intervening portion surrounded by a fibrous capsule. Proximal thrombus conical, and nearly one inch in length. Circumscribed points of adhesion near ligature. No peripheral clot. Circular cicatrix closing the vessel completely and firmly underneath the distal ligature. Intervening portion patent.

Experiment 9. Right femoral artery ligated with medium-sized silk ligatures. Animal killed thirteen days after operation. A large abscess communicated with the seat of the operation, the walls of the abscess surrounding both ends of the vessel. The intervening portion was much shrunken and completely necrosed and separated. Both ends of artery firmly closed. The proximal end contained a very small thrombus. The cicatricial tissue surrounding the artery had drawn the ends together so as to make it appear as though the artery had suffered no loss of continuity.

Experiment 10. Left carotid artery tied with coarse catgut. Animal killed fourteen days after operation. No thrombus. Ligatures and intervening portion surrounded by a firm, fibrous capsule. Ligatures completely encysted, but remained quite firm. A firm, circular cicatrix completely obliterated the artery underneath the proximal ligature. Inner coats not injured. Walls of intervening portion much thickened, and its lumen near distal ligature much contracted.

Experiment 11. Right carotid artery tied with coarse catgut. Animal killed fifteen days after operation. Proximal thrombus nearly three lines in length, almost filling the lumen of the vessel, but non-adherent. No distal thrombus. Ligatures and intervening portion of vessel completely encysted. Size of catgut unchanged. Inner tunics not injured. Obliterating circular cicatrix underneath distal ligature. Lumen of intervening portion diminished in size, and its walls thickened.

Experiment 12. Left carotid artery ligated with fine silk. Animal killed eighteen days after operation. Small proximal thrombus. No distal thrombus. The intervening portion and ligature completely encysted. Lumen of vessel immediately above the distal ligature closed by a fine cicatrix. Lumen of the intervening portion reduced in size. Folds of intima filled with granulation tissue.

Experiment 13. Subcutaneous artery of thigh of sheep ligated with medium-sized catgut. Sheep killed twenty-one days after operation. No thrombi. Ligatures and invervening portion surrounded by spindle shaped mass of connective tissue. Lumen of intervening portion of vessel completely obliterated (Fig. 2).

Experiment 14. Right common carotid artery ligated with fine catgut. Animal killed twenty-one days after operation. No thrombus. Intervening portion, ligatures, and pneumogastric nerve surrounded by a firm capsule of connective tissue. Lumen of intervening portion contracted and filled with granulation tissue, nearer to proximal ligature. Only the knot of the peripheral ligature remained. Firm union underneath the ligature.

Experiment 15. Left carotid artery tied with silkwormgut ligature. Animal killed twenty-five days after operation. No thrombus. Ligature unchanged and encysted. Coats of intervening portion of vessel thickened. Circular cicatrix underneath the proximal ligature, which had cut through the greater portion of the vessel-walls. Intervening portion permeable. Intima presented a roughened appearance.

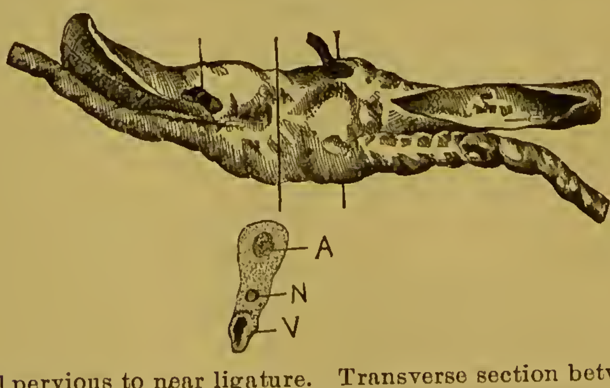
FIG. 2.

Experiment 15a. Right femoral artery tied with fine silk. Animal killed thirty-five days after operation. No thrombus. Ligatures encysted. A firm, fibrous mass between ligatures, in which the lumen of the artery, much reduced in size and nearly obliterated, could be identified. Vessel pervious up to points of ligation (Fig. 3).

FIG. 3.

Experiment 16. Right carotid artery. Catgut ligature. Animal killed after thirty-nine days. No thrombus. Ligatures encysted. Knots distinctly visible. Artery obliterated one-half inch above the peripheral ligature.

FIG. 4.



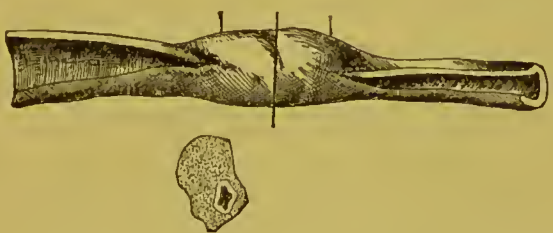
Below, vessel pervious to near ligature. Transverse section between ligatures showed a mass of connective tissue in which the obliterated artery could be distinctly seen (Fig. 4).

Experiment 17. Right femoral artery ligated with coarse silk. Animal killed forty days after operation. No thrombus. Ligatures encysted. Artery on either side of ligatures obliterated to a distance of one-sixth of an inch. Section between ligatures revealed the vessel in a mass of cicatricial tissue, somewhat reduced in size, its lumen filled with a mass of organized tissue (Fig. 5).

Fig. 5.

Experiment 18. Left femoral artery tied with coarse braided silk. Distal ligature just above profunda. Animal killed fifty days after operation. No thrombus. Ligatures encysted. On the proximal ends, the artery was obliterated to a distance of one-eighth of an inch above ligature. Intervening portion converted into a solid string of connective tissue in which the remains of the artery could still be recognized (Fig. 6).

Fig. 6.



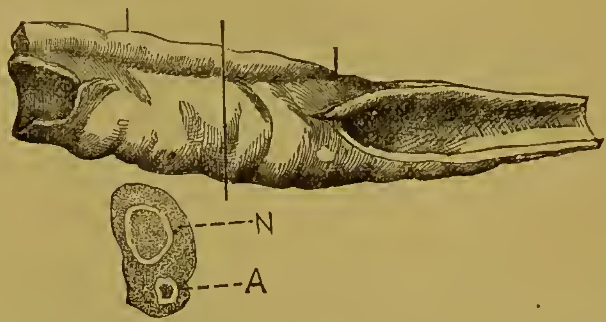
Experiment 19. Right femoral artery. Medium-sized catgut. Animal killed after fifty-two days. No thrombus. Artery pervious to ligatures. No traces of the ligatures could be found. Intervening portion of vessel and vagus surrounded by a spindle-shaped mass of connective tissue in which no distinct traces of the vessel could be found (Fig. 7).

Experiment 20. Right femoral artery. Silkwormgut ligature. Animal killed fifty-five days after operation. No thrombus. On proximal side vessel obliterated to a distance of one-third of an inch; below, three-fourths of an inch from the ligature. Ligatures had apparently cut through the vessel, and were completely encysted. Intervening portion surrounded by a large mass of connective tissue in which the closed lumen of the vessel could plainly be seen.

Experiment 21. Right femoral artery. Medium-sized silk, distal ligature just above profunda. Animal killed after sixty-eight days. Profunda con-

verted into a fibrous cord. In the deep femoral, remnants of a thrombus about one-half an inch in length. Vessel obliterated to some distance. Ligatures cut through. One of them imbedded in a mass of cicatricial tissue in which the intervening portion of the vessel could not be recognized. A small abscess communicated with the seat of the operation, through which one of the ligatures must have escaped.

Fig. 7.



Experiment 22. Left carotid artery of goat tied with catgut. Animal killed after eighty days. Proximal end of vessel obliterated to within the next collateral branch, one-third of an inch below ligature. Distal portion of artery obliterated to same extent, to within one-half an inch of its bifurcation. Ligatures had completely disappeared, and intervening portion was converted into a solid string of connective tissue (Fig. 8).

Fig. 8.

Experiment 23. Right femoral artery of goat tied with silk. Animal killed after ninety days. Artery pervious to within one-half an inch on each side of the ligatures. Ligatures had probably cut through the vessel, and were completely encysted. Intervening portion of vessel transformed into a solid mass of connective tissue about the size of the vessel.

Double Temporary Ligation of Arteries.

Experiment 24. Right common carotid artery of goat tied with coarse catgut; removed twenty-five hours after operation. Animal killed ten days after ligation. At the time the ligatures were removed the circulation in the vessel was interrupted. On examination the artery and the vagus were found surrounded by a copious mass of cicatricial tissue. Interiorly, the vessel

corresponding to the seat of the ligatures was filled and occluded by a small white thrombus projecting into the distal portion of the vessel. Cicatricial tissue in lumen continuous with the para-vascular connective tissue.

Experiment 25. Left femoral artery of goat. Coarse catgut. Removal twenty-four hours after operation. Animal killed nine days after ligation. On removal of the ligatures circulation not interrupted. Ligated portion of vessel considerably smaller. Lumen not obliterated. Inner walls of vessel at the seat of operation studded with minute patches of exudation material, the result of recent endarteritis.

Experiment 26. Left carotid artery. Coarse catgut; removed forty-eight hours after operation. Animal killed ten days after ligation. On removal of ligatures, circulation in vessel not interrupted. An abscess with thick walls communicated with the vessel. The vessel surrounded by a thick fibrous capsule. No thrombus. Lumen of vessel between seat of ligatures narrowed by a copious plastic exudation on that part of the vessel which was in immediate contact with the abscess.

Experiment 27. Left carotid artery. Silk ligature; removed forty-eight hours after operation. Animal killed fourteen days after operation. Circulation not interrupted. Post-mortem appearances the same as in 25.

Experiment 28. Left carotid artery. Silk ligature; removed seventy-two hours after operation. Animal killed thirty-five days after operation. Circulation, on removal of ligatures, interrupted. Proximal clot one and one-third inches in length with circumscribed points of adhesion. Distal clot, none. At seat of operation vessel very much contracted. Lumen filled with remnants of a small clot and granulation tissue.

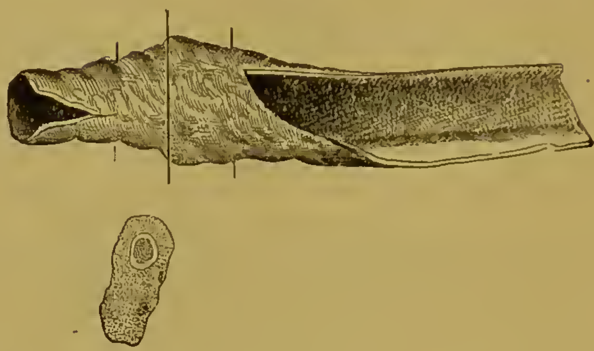
Experiment 29. Left carotid artery. Silk ligature; removed after seventy-two hours. Animal killed thirty-five days after operation. Circulation interrupted. Suppuration followed the removal of the ligatures. Proximal thrombus about two lines in length. Coats of vessel very much thickened. Thrombus adherent by plastic exudation from inner vessel-walls. Distal thrombus very minute. Intervening portion separated at one end, projecting into the abscess cavity. Both ends of the artery permanently obliterated, united, and brought into close approximation by a mass of cicatricial tissue.

Experiment 30. Right carotid artery. Silk ligature; removed seventy-two hours after operation. Animal killed twenty-eight days after ligation. Removal of ligatures followed by suppuration. No thrombi. Both ends of the vessel permanently obliterated and brought into close contact by a mass of cicatricial tissue in which no trace of the intervening portion could be found. Ligated portion of vessel had probably sloughed, and escaped with the contents of the abscess which communicated with the seat of the operation.

Experiment 31. Right common carotid artery, near subclavian. Coarse catgut. Ligatures removed six days after ligation. Animal killed sixteen days after operation. Circulation completely arrested on removal of ligatures. No thrombi. Vessel, at seat of ligatures, surrounded by spindle-shaped mass of connective tissue, in a transverse section of which the artery could be

readily identified, its lumen being filled with embryonal connective tissue (Fig. 9).

FIG. 9.



Experiment 32. Left common carotid artery. Coarse catgut. Ligatures removed six days after operation. Animal killed fourteen days after ligation. On removing distal ligature vessel gave away. No hæmorrhage. Distal end closed by a narrow cicatrix. Very minute thrombus. Thrombus in proximal end two lines in length; firmly adherent. At point of proximal ligature narrow circular cicatrix. Intervening portion of vessel separated at one end. Not necrosed. Both ends of vessel connected by a strong bridge of connective tissue.

Double Ligation of Veins.

Experiment 33. Right jugular vein. Catgut ligature. Animal killed six hours after operation. Minute peripheral thrombus. Increased vascularity of adventitia.

Experiment 34. Left femoral vein. Catgut ligature. Animal killed after twenty-four hours. Filiform distal thrombus; none on the proximal side. Intervening portion completely empty, and slightly adherent to surrounding tissues.

Experiment 35. Right femoral vein. Coarse catgut ligature. Animal killed after three days. Small distal thrombus. Intervening portion adherent to surrounding tissues, containing in its interior a small granulation thrombus.

Experiment 36. Right jugular vein. Coarse catgut ligature. Animal killed after five days. Minute distal thrombus in folds of intima. On removing proximal ligature the inner surfaces of intima were found firmly adherent, evidently by direct union.

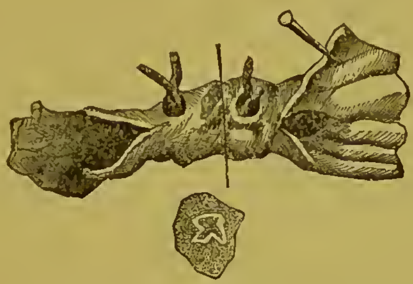
Experiment 37. Right femoral vein. Coarse silk ligature. Animal killed after seven days. Suppuration after operation. Minute peripheral clot. Ligatures encysted. Intervening portion partially destroyed by suppuration. Ends of vessel united by a bridge of connective tissue. Vessel underneath the ligatures obliterated.

Experiment 38. Right jugular vein. Silk ligature. Animal killed after nine days. Suppuration followed the operation. Abscess communicated

directly with the intervening portion of the vessel which had nearly separated. Small truncated distal thrombus, non-adherent. Ends of vessel firmly closed and united by a strong bridge of connective tissue.

Experiment 39. Right jugular vein. Medium-sized silk ligature. Animal killed after twelve days. Minute adherent distal thrombus. Ligatures encysted. Intervening portion surrounded by a capsule of connective tissue. On transverse section the star-shaped lumen of vessel was discernible, firmly closed by young connective tissue (Fig. 10).

Fig. 10.

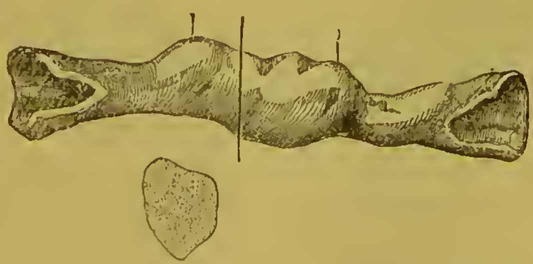


Experiment 40. Left jugular vein. Silk ligature. Animal killed after fourteen days. No thrombi. Ligatures encysted. In removing the proximal ligature firm adhesions between folds of intima. Intervening portion empty, and adherent to surrounding tissues.

Experiment 41. Right jugular vein. Horse-hair ligatures. Animal killed after twenty-one days. No thrombi. Ligatures not encysted, loose upon the remaining parts of the intervening portion. Ends of vessel closed by very narrow cicatrix.

Experiment 42. Right jugular vein. Catgut ligature. Animal killed after thirty-seven days. Ligature encysted. Vessel obliterated to a distance half an inch from ligatures on both sides. Intervening portion a solid string of connective tissue in which no traces of the vessel could be found (Fig. 11).

Fig. 11.



Experiment 43. Right jugular vein. Coarse silk ligature. Animal killed after forty-nine days. Vessel pervious to near ligatures. Ligatures encysted.

Intervening portion surrounded by a mass of connective tissue in which the obliterated vessel could be readily identified (Fig. 12).

Fig. 12.

Experiment 44. Right femoral vein. Medium-sized silk ligature. Animal killed after fifty-four days. Vessel pervious to near ligatures. Ligatures had evidently cut their way through the vein and were encysted in the cicatrix. Intervening portion transformed into connective tissue (Fig. 13).

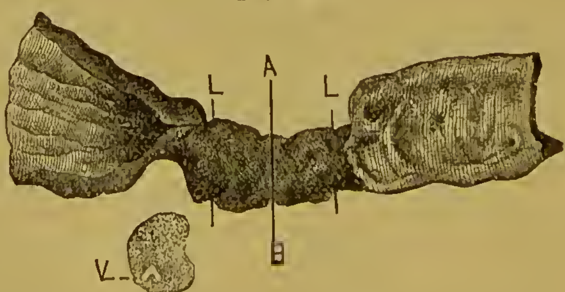
Fig. 13.

Experiment 45. Right jugular vein. Medium-sized catgut. Animal killed after eighty days. Ligatures absorbed. Intervening portion transformed into connective tissue.

Double Temporary Ligation of Veins.

Experiment 46. Right jugular vein of goat. Silk ligature, removed twenty-four hours after operation. Animal killed ten days after operation.

Fig. 14.



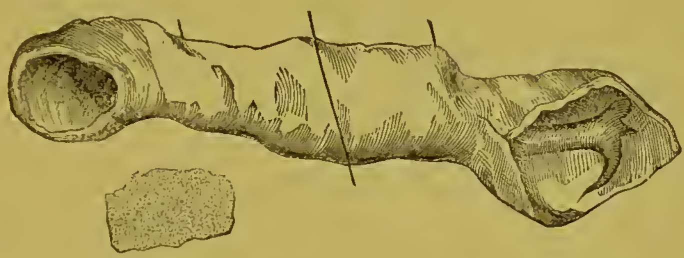
Circulation on removing ligatures not arrested. Intervening portion contracted by a mass of intramural and para-vascular cicatricial tissue, but patent. Intima normal in appearance. An abscess communicated with the

seat of the operation, only in the coats of the vein intervening between it and the lumen of the vessel.

Experiment 47. Left jugular vein. Silk ligature, removed forty-eight hours after operation. Animal killed thirty-four days after ligation. Circulation arrested. No thrombi. Intervening portion of vessel transformed into a firm string of connective tissue, in which no trace of the original structure could be recognized (Fig. 14).

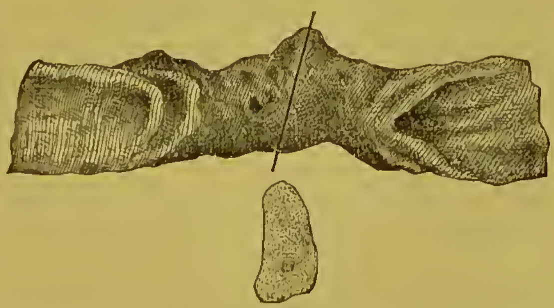
Experiment 48. Right jugular vein. Silk ligature, removed three days after operation. Animal killed twenty-seven days after ligation. Circulation arrested at seat of ligatures. Peripheral clot narrow, partially adherent, one inch in length. At the seat of operation about two lines of the vessel converted into a solid string of connective tissue (Fig. 15).

FIG. 15.



Experiment 49.—Left jugular vein. Coarse silk ligature, removed three days after operation. Animal killed forty days after ligation. Circulation interrupted. No thrombi. Intervening portion converted into a massive string of connective tissue (Fig. 16).

FIG. 16.



Experiment 50. Left jugular vein. Coarse silk ligature removed four days after operation. Animal killed thirty-five days after ligation. Circulation interrupted. A short truncated peripheral clot adherent at its base. Constricted portion of vessel almost but not completely obliterated. Folds of intima filled with recent connective tissue, bridges of same material spanning the lumen of the vessel. The surface of the intima corresponding to the wound covered by a copious plastic exudation.

Experiment 51. Right jugular vein. Coarse catgut ligature, removed after six days. Animal killed fifteen days after the operation. Suppuration followed the operation. Circulation arrested. An immense white peripheral thrombus adherent at its base. Vessel at seat of distal ligature obliterated by a narrow cicatrix. Intervening portion contracted, walls thickened, circumscribed patches of exudation underneath the proximal ligature.

Experiment 52. Right jugular vein. Coarse catgut, removed after six days. Animal killed fourteen days after operation. Vein completely obliterated at points of ligation. Intervening portion surrounded by a dense capsule of connective tissue, a transverse section of which shows the lumen of the vessel almost completely obliterated by plastic exudation.

Ligation of Artery and Vein in a Horse.

Experiment 53. Right carotid artery. Silk ligatures. Animal died eight days after operation, death being caused by chloroform during the second experiment. Proximal clot extending to near subclavian, partly adherent; distal clot eight lines in length, extending beyond nearest collateral branch. Ligatures encysted. Intervening portion surrounded by a capsule of connective tissue. Walls thickened. Beginning cicatrization under peripheral ligature.

Experiment 54. Right jugular vein of same animal. Coarse silk ligature. Large distal thrombus completely distending the vein, and extending beyond bifurcation. Ligatures encysted. Proximal portion of vein diminished in size. Intervening portion surrounded by a capsule of connective tissue. Underneath proximal ligature firm adhesions between folds of intima.

XXIII. Remarks.

1. Effect of Suppuration.

The deleterious influence of suppuration on the process of cicatrization is well illustrated by these experiments. In all cases where the wound healed by primary union, the isolated portion of the vessel became adherent to the adjacent tissues as early as the second day, and, after a few days more, the interrupted vascular connections were restored. In all cases, with the exception of experiments 9, 21, 37, and 38, where the wound was not reopened for the purpose of removing the ligatures, the wound healed by primary union, and cicatrization in the vessel progressed in a favorable manner. In using the temporary ligatures, suppuration was a more frequent concomitant on account of the necessary interference with the reparative process in the wound, and the increased difficulties encountered in preventing infection. Suppura-

tion supervened in experiments 26, 29, 30, and 50, with the temporary ligature, so that this event occurred eight times out of fifty-five, the whole number of experiments.

In all cases where suppuration followed the operation the vitality of the intervening portion of the vessel was destroyed in part or in its entirety, and if a sufficient length of time had elapsed, this portion of the vessel was usually found completely separated and within the abscess cavity. Secondary hæmorrhage, however, was never observed as the result of suppuration, or sloughing of the intervening portion, as the narrow intra-vascular cicatrix in both ends of the vessel was usually supported by a strong para-vascular ring of connective tissue which formed a part of the thick walls of the abscess. In all these cases the vessels had invariably suffered a loss of continuity by the ligature. These facts force upon us the following conclusions:

1. All surgical operations on blood-vessels should be performed under strict antiseptic precautions for the purpose of preventing suppuration.

2. In aseptic wounds the complete isolation of a vessel from its sheath for a distance of one inch is not followed by any serious disturbance of nutrition in the vessel-walls.

3. Suppuration invariably produces a loss of continuity of the vessel at the seat of ligature.

4. Inflammation beyond the limits of the reparative process interferes with the typical formation of the intra-vascular cicatrix.

2. Thrombus.

For nearly fifty years the idea has prevailed, and to a great extent is still prevalent, that in applying a ligature to an artery, a thrombus forms on the proximal side, which extends to the nearest collateral branch, and that by organization of the clot the vessel is obliterated to the same extent. All authors who attribute definitive vessel closure to organization of a thrombus, assert that the latter always precedes cicatrization, and that when thrombus formation fails to take place, permanent obliteration of the ligated vessel is an impossibility. I have shown elsewhere that thrombosis does not necessarily follow every case of ligation, in fact, that it very often fails to take place, and yet definitive closure takes place as promptly

as though a thrombus had formed. Coagulation of the blood means necrosis or death of the morphological elements of the clot, and as such an occurrence, it is more likely to result from conditions unfavorable to the process of cicatrization. Severe traumatic injuries of the vessel and, more particularly, an infectious inflammation of the seat of operation, are conditions which favor the formation of a thrombus.

In my experiments on arteries I find that in thirty-four cases the presence of a proximal thrombus is mentioned thirteen times to ten in the distal portion of the artery. In four of the experiments it is noted that only a peripheral thrombus formed in seven cases in which the thrombus was found only on the proximal side of the ligature. In most of the cases the thrombus was quite minute, seldom filling the entire lumen of the vessel, and never adherent to the inner surface of the vessel. A notable exception was furnished by the experiment on a horse, where an immense proximal and distal thrombus formed, filling the entire lumen of the vessel, extending on the proximal side to near the subclavian artery, and on the peripheral, to beyond the bifurcation of the vessel.

In the specimens derived from twenty-one experiments on veins I was never able to find even a trace of a thrombus on the proximal side of the ligature, while the presence of a distal thrombus was noted eleven times, or in a little more than fifty per cent. of all the cases. These experiments furnished the most favorable opportunities to study the process of cicatrization underneath the proximal ligature independently of a thrombus, as the presence of a clot was excluded in every instance. With the exception of the specimen obtained from the horse, the thrombi in veins were also usually small in size, and seldom adherent over any considerable surface. Only in exceptional cases, both in arteries and veins, did the thrombus reach as far as the nearest collateral branch. The results of these experiments render it obvious that the time-worn rule laid down in most of our text-books on surgery, which directs the operator to apply the ligature in such a manner as to leave a space of one inch or more between the ligature and the nearest proximal collateral branch for the purpose of insuring the formation of a thrombus, is wrong, both in theory and in practice, and should no longer be followed as a guide in deciding upon the seat of ligature.

3. Ligature.

All ligatures were made strictly aseptic, and in all instances where suppuration did not follow the operation, they were encysted, irrespective of the material used. Silk, silkwormgut, and horsehair were not affected by the granulating process, but were always found unchanged in the cyst. In all aseptic wounds the loop of the ligature was found covered completely by the swollen adventitia after the first forty-eight hours. A great contrast was observed between the catgut ligature and ligatures made of material not susceptible to absorption, as far as their effect on the vessel-walls was concerned. Catgut applied itself easily and smoothly to the exterior of the vessel-walls, and by becoming softened and infiltrated with cells, it appeared to constitute a part and parcel of the vessel-tissues until it was replaced by substitution by a ring of organized tissue, which served as a material support to the vessel until cicatrization was completed, thus preserving the continuity of the vessel.

All the remaining kinds of ligatures appeared to act as foreign bodies as far as the vessel tunics were concerned, and invariably produced a solution of continuity after a sufficient length of time had elapsed. They were usually found encysted in the mass of connective tissue between, and some distance from, the ends of the vessel. Catgut, on the other hand, did not manifest this tendency It became encysted, and underwent absorption *in situ.* The earliest time in which the catgut ligature was found absorbed was twenty-one days, in experiment 14, where only the knot remained. In experiment 19, where fifty-two days had elapsed after the operation, no trace of the ligature could be found, For the following obvious reasons, catgut recommended itself as the most desirable and efficient material:

1. If catgut is well prepared it will resist absorption until definitive obliteration of the vessel has taken place.

2. It does not act as a foreign body, and does not destroy the continuity of the vessel.

3. It is completely absorbed and replaced by organized tissue, which furnishes an additional support to the vessel-walls at the seat of cicatrization.

4. Extra-Vascular Cicatrix.

The first attempt at obliteration of a blood-vessel after ligature is manifested in the connective tissue of the adventitia and the para-vascular connective tissue. As early as twenty-four hours after ligation, the isolated portion of the vessel has become adherent to the surrounding tissues, and the swollen adventitia overlaps and covers the loop of the ligature. The connective tissue becomes very vascular, and undergoes rapid embryonal transformation, being converted in a few days into granulation tissue which completely surrounds and embraces the ligatures, the intervening portion, and the vessel-ends as the provisional callus incloses the ends of a fractured bone.

This capsule of connective tissue was found present in every specimen, and in many instances was of remarkable size and strength. The thickest portion of the capsule always corresponded to the locality which had been subjected to the greatest amount of traumatism, that is, the side of the vessel towards the operation wound. As soon as definitive closure of the vessel had taken place, the capsule diminished in size, until after a period of three months it did not exceed the original diameter of the ligatured vessel.

The contraction incident to all cicatricial tissue manifests itself also in the spindle-shaped mass of connective tissue which forms around vessels after ligation, and renders material assistance in the process of obliteration by compressing the vessel, thus diminishing its lumen. In all of our experiments where union of the operation wound occurred without suppuration, the intervening portion of the vessel was found covered by granulation tissue as early as the third day, and the fibrous capsule was always firmly adherent to it. Through the medium of this connective-tissue capsule the ligated ends of the vessel always formed firm adhesions with the surrounding structures, the artery, vein, and nerve often being enveloped by one common capsule, as may be seen well illustrated in Fig. 4.

5. Intra-Vascular Cicatrix.

The inflammatory tissue production proceeds by continuity from the adventitia in a central direction towards the lumen of the vessel until the connective-tissue proliferation perforates the endothelial lining of the intima, an event which initiates the formation of the

intra-vascular cicatrix. Simultaneously with the appearance of the granulation process in the intima and the appearance of new vessels from the adventitia, the endothelial cells assume an active part in the process of cicatrization, the new tissue elements mingling with the connective-tissue product and assisting them in the formation of the internal or definitive cicatrix.

Cicatrization begins always underneath and in the immediate vicinity of the ligature. This fact receives a satisfactory explanation by assuming that the greatest amount of traumatism is inflicted at this point, and that by interrupting the circulation in the vasa vasorum by the ligature, an active engorgement is produced, which accelerates tissue changes and the formation of new vessels; at the same time the inner surfaces of the intima are here brought into accurate and uninterrupted contact. In my experiments on arteries three days was the shortest period of time in which a narrow firm cicatrix formed underneath the proximal ligature (Experiment 3).

In the experiments on veins the condition of the vessel was always examined underneath the proximal ligature, inasmuch as any changes in the tunics and lumen of the vessel at this point had to be attributed to the tissues themselves independently of a bloodclot; as the intervening portion was always made bloodless, and a thrombus was never found on the proximal side of the ligature. In the specimen derived from experiment 36, I found a firm circular cicatrix underneath the ligature on the fifth day. The intervening portion of the vessel was carefully examined at times ranging from six hours to ninety days after the operation. This portion of the vessel, although deprived of all vascular supply, never necrosed unless suppuration followed the operation. Nutrition was sustained by plasma derived from para-vascular tissues until the interrupted circulation in the vasa vasorum was established, when the vessel tunics were again brought into a condition capable of entering into active tissue proliferation. In many of the specimens it was noted that the walls of the intervening portion were found thickened, which would certainly indicate that the tissues did not remain in a passive condition, but were actively engaged in the work of tissue proliferation.

The earliest time at which granulation tissue was found upon the free surface of the intima was seven days in the case of arteries (Experiment 4), and three days in the case of veins (Experiment 35.)

The formation of the cicatrix in the lumen of the vessel always began near the ligatures, the material filling the folds of the intima often forming distinct bridges connecting the highest points of adjacent ridges. In several instances I observed the greatest amount of exudative tissue on that surface of the vessel which was directed towards the wound. The amount of granulation material in the lumen of the vessel appeared to vary; in some specimens the lumen presented a stellate shape, the surfaces of the intima adherent with a minimum amount of material between them (Fig. 10), while in other specimens a cylindrical mass of embryonal connective-tissue occupied the interior of the vessel (Fig. 5). Complete obliteration of the intervening portion took place in the femoral artery thirty-five days after operation (Experiment 15a), after thirty-nine days in the carotid (Experiment 16), and after twelve days in the jugular vein (Experiment 39).

As cicatrization advances the original structures of the tunics disappear, the endothelia are transformed into connective tissue, and between the para-vascular and intra-vascular cicatrices the elastic and muscular tissues undergo degeneration and are removed by absorption. The ultimate effects of the ligature are obliteration of the lumen and conversion of all the tunics of the vessel into a solid string of connective-tissue which is again destined to undergo various degrees of atrophy.

6. Temporary Ligature.

The experiments with the temporary ligature were made with a view to ascertain *intra vitam*, the time required for definitive closure to take place after ligation. In arteries where the ligatures were removed twenty-four and twenty-five hours after ligation, and the animals killed on the tenth and ninth days, no definitive closure had taken place, but the specimens presented evidences of arteritis and endarteritis. In experiment 29 the carotid artery was ligated and the ligatures were removed seventy-two hours after operation, when the circulation was found completely interrupted; and the specimen obtained thirty-five days after operation showed that the vessel had been completely divided by one of the ligatures, but that both ends were permanently obliterated. In experiment 31 (carotid artery) the ligatures were removed after six days, and the specimen obtained sixteen days after operation showed that the intervening portion was

undergoing definitive obliteration, its contracted lumen being filled with a small granular thrombus (Fig. 9).

In the veins the temporary ligature appeared to produce its effects in a shorter time and with a greater degree of certainty. In two experiments on the jugular vein (experiments 47 and 48) the ligatures were removed after forty-eight hours, and in both cases the circulation was completely and permanently arrested; and the specimens obtained thirty-four and twenty-seven days after operation showed that the intervening portions had been converted into strings of connective tissue (Figs. 14 and 15).

From these experiments it appears that in arteries the size of the carotid, at least three days are required for the cicatrix underneath the ligature to become sufficiently firm to resist the intra-arterial pressure independently of the ligature, while in the jugular vein the same object is accomplished in two days.

7. Microscopical Appearances of the Recent Intra-Vascular Cicatrix.

I shall not attempt to give a detailed account of the microscopical appearances of the different tunics at different and successive stages during cicatrization, but shall describe briefly the embryonal tissues which are found within the lumen of the intervening portion of the vessel and its immediate boundaries. These observations were made on transverse sections through the intervening portion equidistant from the ligatures. Figure 17 represents the inner border of the wall of the femoral artery and a portion of its lumen, in a transverse section of the specimen obtained from experiment 19, fifty-two days after operation, and illustrated by Fig. 7. The open lumen of a small vessel can be seen in the intima near its inner border. From the intima projections of connective-tissue proliferation are seen to penetrate into the lumen of the vessel, pushing before them the endothelial lining, and perforating it at different points, forming subsequently a network of connective tissue in the interior of the vessel, in the meshes of which are seen masses or nests of new endothelial cells, also products of the pre-existing endothelial elements. At certain places the endothelial cells assume an oval and spindle-shaped form prior to being transformed into connective tissue. Blood-vessels from the intima accompany the projections of connective tissue into the lumen of the vessel.

Figure 18 represents a transverse section through the intervening portion of the jugular vein, obtained forty-nine days after operation from experiment 43, and illustrated by Fig. 12. It shows the intima and a portion of the granulation thrombus which has permanently closed the lumen of the vessel. The microscopical appear-

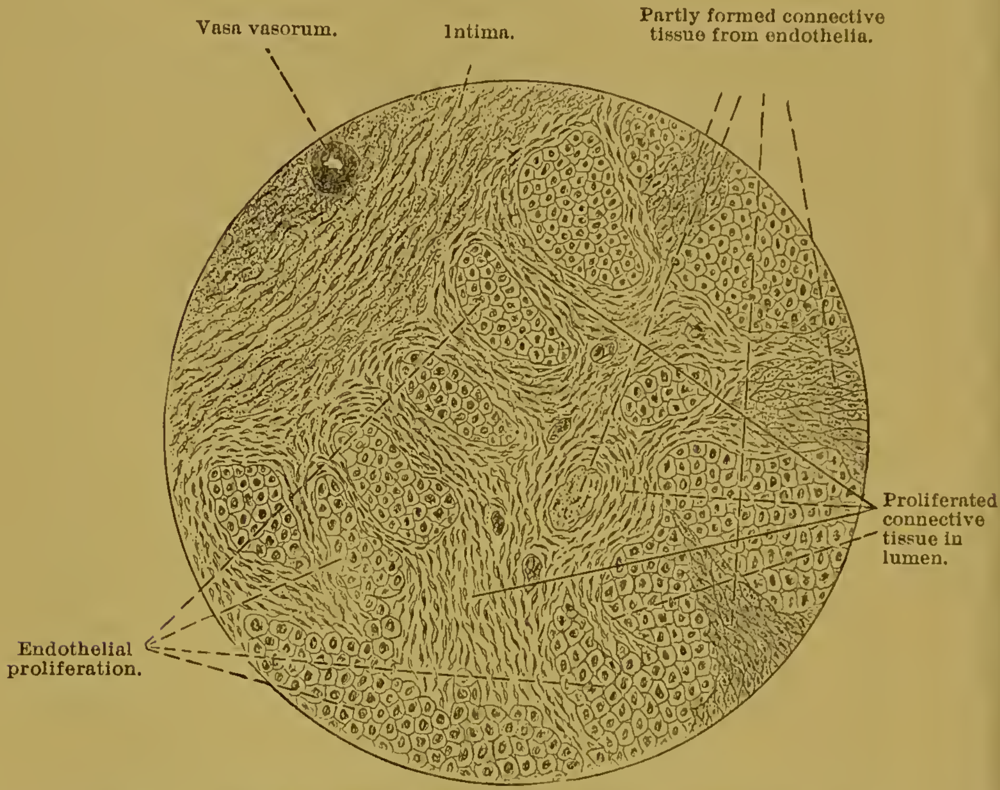


Fig. 17. Microscopical appearances presented by specimen from experiment 19. Transverse section through border of artery. × 240.

ances are almost identical with the arterial specimen. Both of these illustrations furnish the best possible demonstration of the manner in which the intra-vascular cicatrix is formed from the connective tissue and endothelia. The macroscopical and microscopical examination of the specimens are alike confirmatory of the assertion that the intra-vascular cicatrix is the exclusive product of connective tissue and endothelial proliferation.

XXIV. Practical Suggestions.

The results of my own experiments, as well as the literature on the subject, tend to prove that all kinds of ligatures, provided they have been made aseptic, always become encysted in aseptic wounds. All ligatures, however, which permanently resist absorption, destroy the continuity of the vessel, and on this account, instead of adding

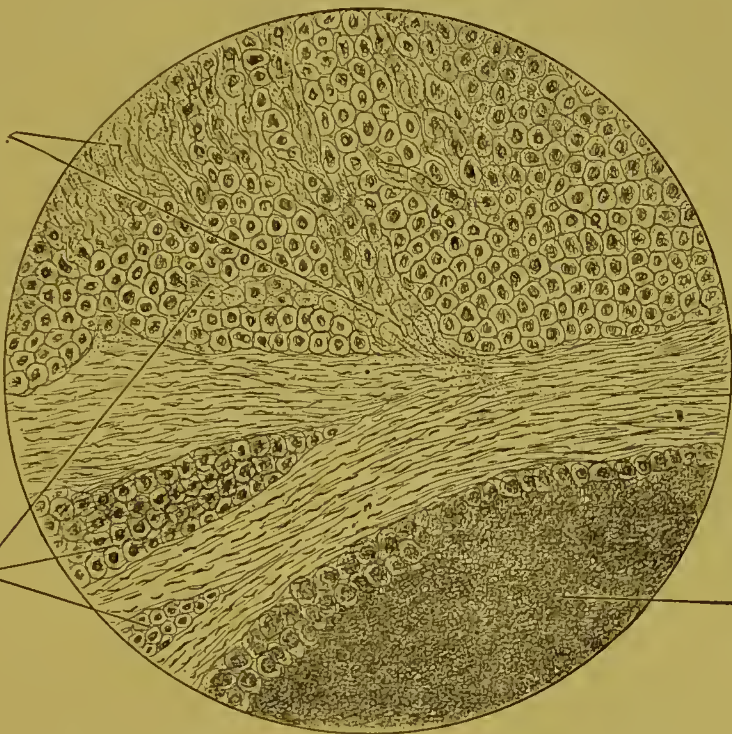


Fig. 18. Microscopical appearances presented by specimen from experiment 43.

Transverse section of part of vein in ligated portion. × 240.

strength to the para-vascular cicatrix, weaken the vessel-walls at the seat of ligation. I have never observed a single case in hospital or private practice where the catgut ligature failed to fulfill in the most satisfactory manner the purposes of a provisional hæmostatic agent until the definitive cicatrix had become sufficiently firm to resist the intra-arterial pressure. In place of severing the tunics of the ligated vessel the catgut ligature is gradually displaced by organized tissue which increases the resisting capacity of the vessel, providing an

additional safeguard against secondary hæmorrhage if from any cause definitive obliteration is retarded. In enumerating the superior advantages of the catgut ligature, Nussbaum says: "The most careful microscopical examinations have shown that catgut increases to a considerable extent the resisting capacity of an artery in forming firm connective-tissue connections with the vessel."[1]

The aseptic animal ligature possesses two distinct and important advantages over all permanent ligatures: 1. It does not necessarily destroy the continuity of the vessel. 2. It gives additional strength to the extra-vascular cicatrix. These advantages recommend the animal ligature more particularly for the purpose of tying a vessel in its continuity. I am firmly convinced that in many of my experiments the internal tunics of the arteries remained intact after ligation, and yet cicatrization progressed in a satisfactory manner. Hence it is no longer necessary to tie the ligature so firmly as to crush the tunics of the vessel. All that is necessary is to tie with sufficient force to approximate the inner surfaces of the intima with a view to insure effective provisional obliteration of the vessel, when cicatrization will follow as a necessary result, provided the vessel tunics are in a healthy condition. If cicatrization in a vessel takes place from the fixed cells of its tunics without the formation of a thrombus, it will be seen that in many instances a vessel can be ligated with safety in its continuity close to a collateral branch, when existing circumstances dictate such a course.

One of the rules invariably given by authors in surgery of the blood-vessels was to make a small opening in the sheath of the vessel, only of sufficient size to permit of passing the ligature needle around it. It was feared that a more free opening in the sheath and a more extensive isolation of the vessel would lead to necrosis of its tunics on account of the cutting off of the vascular supply. That this idea still prevails is evident from one of the most recent text-books on surgery. Lidell calls special attention to this point in the following language: "The risk of sloughing, however, arises mainly from isolating the artery too much, or from separating it too extensively from its sheath, while dissecting to expose it, or while preparing to pass a thread around it, whereby the minute vessels which nourish its coats are too extensively destroyed; hence

[1] Op. cit.

the dangerousness of passing a spatula or the handle of a scalpel under the artery, and of dragging it out of its bed when tying it."[1]

All of these fears are unfounded when operating under antiseptic precautions. In all my experiments I did all that is here cautioned against: I isolated the arteries and veins from their sheaths for an inch or more, and dragged the vessel near to the surface of the wound in applying the second ligature, and yet I never observed any sloughing except in the cases where the operation was followed by suppuration. I am strongly in favor of opening the sheath freely, so that the operator can not only feel but *see* what he is doing, and I am convinced that by pursuing this course there is less harm done than by operating in the dark.

My experiments on the veins have taught me another important and practical lesson, viz., their tolerance to traumatic insults. In not one of the cases was death produced by the operation, although in a few of the animals both the jugular and femoral veins were tied at different times. I never observed progressive phlebitis, embolism, or pyæmia. Veins, like those of the peritoneum, may be contused. torn, lacerated, cut, punctured, burned, and ligated with impunity, if infection is avoided. Veins are exceedingly prone to infection, but if infection can be prevented their injuries are repaired with wonderful rapidity. As regards the time required for definitive obliteration to take place, the results of the experiments would indicate that in the case of arteries of the size of the carotid or femoral from four to seven days are necessary, while in the jugular vein the same object is accomplished in three to four days.

The double catgut ligature may be resorted to with advantage in the human subject in ligating large vessels in their continuity, more especially if the operation is done near a collateral branch, as it approximates the inner surfaces over a larger area and thus furnishes a more extensive surface for cicatrization. The practicability and utility of the double ligature is, however, rendered most apparent in the treatment of varicose veins. For many years I have successfully used the subcutaneous double catgut ligature in the treatment of varicocele. In operating on varicose veins of the lower extremity, the intervening portion can readily be rendered bloodless by applying an Esmarch's bandage before tying the

[1] Injuries of Bloodvessels. The Internat. Encycl. of Surgery, vol. iii, p. 90.

ligatures. The entrance of blood into the vessel between the ligatures through small collateral branches can be prevented and the process of cicatrization materially assisted by applying an antiseptic compress over the seat of the operation before removing the elastic bandage.

A careful examination of the literature on this subject, as well as the results of my own investigations, warrant me in submitting the following conclusions:

1. All operations on blood-vessels should be done under antiseptic precautions.

2. The aseptic catgut ligature is the safest and most reliable agent in securing provisional and definitive closure of blood-vessels.

3. A thrombus after ligature is an accidental formation which never undergoes organization and takes no active part in the obliteration of the vessel.

4. The intra-vascular or definitive cicatrix is the exclusive product of connective tissue and endothelial proliferation.

5. Permanent obliteration in arteries takes place in from four to seven days, in veins, in from three to four days.

6. In ligating vessels in aseptic wounds the vessel sheath can be opened freely without compromising the integrity of the vessel tunics, and this procedure renders the operation safer and easier of execution.

7. The double aseptic catgut ligature should be preferred to the single ligature in ligating large arteries in their continuity near a collateral branch, and should always be employed in all operations of tying varicose veins in their continuity as the safest and most effective measure in the production of definitive obliteration.

AN EXPERIMENTAL AND CLINICAL STUDY OF AIR-EMBOLISM.[1]

Sudden and unexpected death during an operation is a calamity which never fails to strike terror to the heart of the boldest surgeon. Although death is a frequent and familiar visitor wherever human beings exist, nevertheless its sudden and unforeseen advent conveys with it more than the usual halo of sadness, and when such a scene transpires in the operating room it leaves impressions which neither time nor space can erase. Disasters of this kind come without warning and usually at a time when least expected.

The surgeon who has the misfortune to meet with such an accident is not only destined to burden his memory with the unpleasant remembrances of the incident for the remainder of his days, but in addition he is often made an unjust object of reproach by those who are unable to appreciate the nature of the case. His conscience may be relieved by a favorable verdict regarding his conduct and management of the case before the only competent tribunal, composed of his colleagues and medical press, but that most uncertain of all things, public opinion, will, in all probability, be arrayed against him. In one sad moment the object of his ambition, the ultimate aim of his lifework has suffered irreparable loss.

The surgeon who seeks to maintain and advance the interests of his profession as well as his own reputation, should familiarize himself with all the causes and conditions which may precipitate such an unhappy result, with a view to adopt and apply timely prophylactic measures. Believing that it is good practice to prepare for war in time of peace, I intend to call attention to one of the most dreaded and, I may add, one of the most uncontrollable causes of sudden death; I allude to air-embolism.

After consideration of the subject from an historical, experimental, and clinical standpoint, I shall endeavor to point out the

[1] Read before the American Surgical Association, 1886.

conditions, remote and direct, which give rise to this accident. The different explanations of the immediate cause of death will be discussed and, finally, I shall offer some practical suggestions relating to prophylactic and therapeutic measures.

By air-embolism, I understand the presence of free atmospheric air within the vascular system during life and in sufficient quantity to give rise to symptoms of obstruction. It is a true embolism inasmuch as the location of the volume of air which constitutes the embolus is always some distance from its point of entrance. The presence of air in a vessel offers the same mechanical obstruction to the flow of blood as a solid substance, and gives rise to the same disturbance of circulation in the tissues supplied by the vessel.

An air-embolus differs from an ordinary embolus in that, when once introduced into the circulation, it is capable of being broken up or divided by the blood current and the action of the heart, and on this account usually becomes the source of multiple emboli. It also differs pathologically from a solid embolus, since it is more likely to be removed by absorption and is less liable to be followed by thrombosis. Air-embolism is always due to the introduction of atmospheric air into a wounded or injured vein, and, in contradistinction to the ordinary form of embolism, it is primarily almost always formed in the right side of the heart and in the venous system. In order to study the immediate effects of the presence of a considerable amount of air on the heart and the vessels, it becomes necessary to allude to the experiments where embolism was artificially produced by the introduction of solid substances into the circulation.

I. The Immediate Cause of Death in Rapidly Fatal Embolism.

The most interesting experiments on embolism were made by Virchow, in 1847, and by Panum, in 1854-1855, and although the conclusions of these experimenters are somewhat at variance, our present knowledge on this subject is based upon the conjoined labors of these distinguished writers.

Virchow was convinced that his experiments were conclusive in showing that complete embolism of the pulmonary artery would

invariably prove fatal in a short time, while partial obliteration of this vessel produces either no symptoms at all, or only temporary dyspnœa, restlessness, and a sense of oppression. He gives the following explanation to account for the immediate cause of death in cases of complete obstruction of the pulmonary artery by a large embolus:[1] "The first effect of the pulmonary ischæmia is the interruption of the supply of oxygenated blood to the coronary arteries of the heart and the arteries of the body, as well as the stasis of the venous blood in the right side of the heart, the coronary veins, and the veins throughout the body. These conditions result in the arrest of the heart's action in the diastole, the tetanic contractions of the voluntary muscles, the retardation of respiration, the dilatation of the pupils, the protrusion of the eyeballs, etc., and very soon complete death."

Panum, by a series of very ingenious experiments, disproved the assertions of Virchow, that a lack of arterial blood in the coronary arteries produces instantaneous arrest of the heart's action.[2] In a rabbit, where the ventricular contractions had ceased for fully fifteen minutes and where only the right auricle continued to pulsate, he injected a warm black mass, composed of tallow, wax, and soot, into the aorta, for the purpose of studying more accurately the anatomical relations of the coronary arteries. The injection penetrated the smallest vessels. The right auricle continued its rhythmical movements for three hours and a half after the injection was made, the heart and lungs having been removed from the body.

In a second experiment he divided both pneumogastric nerves in a dog, and then opened the chest and the pericardium and passed a double ligature underneath the innominate artery; after tying the upper ligature and drawing the lower tight, the artery was opened between them, and a silver tube introduced and secured in the vessel with the proximal ligature. The silver tube was connected with a glass tube by a piece of rubber tubing. To the distal end of the glass tube another piece of rubber was attached and all the tubes filled with oil, which was prevented from escaping by a clamp. The aorta was compressed with a spring forceps above the origin of the innominate artery and the same black mass was injected through the tubes into the aorta. The oil and black mass entered the vessel,

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[1] Gesammelte Abhandlungen, p. 297.

[2] Exper. Beiträge zur Lehre v. d. Embolie. Virchow's Archiv, xxv. p. 308.

and after closing the aortic valves filled the coronary arteries, which were found completely blocked with the foreign substance.

The movements of the heart were carefully observed before, during, and after the injection was made. Before the injection, the contractions were regular, eighty to ninety per minute; during the injection, on account of the higher temperature of the injection (45° C.), the contractions became more rapid, and in the left side of the heart, which was distended with blood, they were less forcible, an occurrence which could be readily accounted for by the mechanical obstruction to the outflow from the left ventricle. All the chambers of the heart continued to contract for five minutes after the injection was complete. Six minutes after the injection was made, the contractions of the left auricle ceased. The movements of the ventricles were feeble, but could be plainly seen. The rhythm of the ventricular contractions grew slower than the contractions of the right auricle, and at the same time were less regular.

After twenty-five minutes the right auricle pulsated forty-eight, the ventricles twenty-four times per minute. Five minutes later the pulsations of the auricle and ventricles were the same in frequency. Forty minutes after the injection the ventricles contracted twenty-four times per minute to eight auricular pulsations. Fifty minutes after the injection the ventricles made twenty-three rhythmical movements to three of the auricles. After one hour the movements of the heart again became regular, inasmuch as the auricles and ventricles pulsated thirteen times per minute, and in such a manner that the movements of the ventricles followed immediately after the contraction of the auricles and were followed by a long diastolic pause.

Seventy-five minutes after the injection, the movements of the left ventricle ceased, while the right half of the heart contracted regularly eight times per minute. Two minutes later the ventricle contracted only twice to eight movements of the auricle. Ninety minutes after the injection, the right ventricle ceased to beat, while the right auricle continued to contract for six hours and ten minutes after the injection, making toward the last only one movement per minute. After all pulsations had ceased for a while, they were renewed by blowing upon the heart. These contractions continued for seven hours and a half after the injection, and even after they had ceased for a second time they were again excited by mechanical irritation.

During this observation the heart was kept at a temperature of 12.5° to 13° C. under a glass bell in which the air was saturated with moisture. An examination of the heart showed that the coronary arteries were completely distended with the black mass, and that the capillary vessels and coronary veins were blocked with oil. A few drops of oil, but nothing of the black mass were found in the right auricle. The aorta near the heart was filled with the injection material, and the aortic valves were so completely closed that nothing had penetrated into the ventricle. In two other instances the coronary arteries were made impermeable in a similar manner, and the contractions of the heart were temporarily arrested by electric irritation of the pneumogastric nerves. This experiment was repeated in both animals more than twenty times, and always with the same uniform result. If the electric stimulation was continued after the heart had ceased to contract, the movements were again excited, but this always required a continuation of the current for at least a minute. If the electrodes were removed after the heart ceased to act, it required twenty seconds before the contractions were re-established, the movements being always more rapid than before the irritation was applied.

From these experiments we are forced to conclude that embolism of the coronary arteries is insufficient to produce instantaneous arrest of the heart's action. Virchow quotes Erichsen as having observed prompt cessation of the movements of the heart after ligation of the coronary arteries, but Panum doubts the possibility of performing this operation upon the heart of a living animal.

The same observer studied embolism of the pulmonary artery by injecting an emulsion of gum-arabic, in which were suspended small pellets of black wax, into the jugular vein of a medium-sized dog. Eight cubic centimeters of the emulsion were injected. All signs of life and all reflex movements ceased three minutes after the injection. After death the large vessels were tied, in order to ascertain the exact quantity of blood contained in each side of the heart. The right side contained 112.35 grammes of dark-colored blood, the left contained only 6.45 grammes. In another experiment he injected coarsely powdered charcoal in suspension, into the jugular vein of a dog. The time which elapsed between the injection and cessation of life was longer than in the preceding case, consequently the left heart contained a larger amount of blood, although the

quantity was small when compared with that in the right side of the heart.

In all cases of death resulting from embolism of the pulmonary artery, the amount of blood found in the left side of the heart is proportionate to the completeness of the obstruction in the pulmonary artery. The left side of the heart is never found completely empty, as the labored respiratory movements will force the blood, which is present in the pulmonary vein and its branches, into the left side of the heart. If instead of using small emboli large plugs are injected, as was done by Virchow, the blood contained on the distal side of the obstruction will pass through the pulmonary circulation and reach the left side of the heart, consequently in such cases more blood will be found in the left ventricle.

Panum asserts also that cessation of the heart's action does not invariably take place so early that it can be considered as the primary and direct cause of death. As a rule, he found the heart pulsating after the death struggle had been initiated from arrest of innervation from the cerebro-spinal center. In some instances the heart continued to pulsate after all signs of animal life emanating from the brain and spinal cord had ceased. Shortly after respiration was arrested the heart did cease to pulsate, and, as Virchow has stated, in the diastole.

According to Panum, the cessation or continuation of the heart's action exerts no influence for good or evil in cases of extensive embolism. He claims that if the cessation of the heart's action takes place as one of the first effects after embolism of the pulmonary artery, as was noted in Virchow's first case, it must be regarded, under certain circumstances, as being the result of irritation of the pneumogastric nerves, and so much the more as the heart, in the case referred to, again began to pulsate after the thorax was opened. As a rule, the heart's action is arrested by distention of the right ventricle.

Other observations tend to show that the distention of the right ventricle is the cause. The excess of carbonic acid gas and the diminished supply of oxygen must also be taken into account. Other experiments have demonstrated that carbonic acid, in concentrated form, injected into the heart after its removal from the chest, readily leads to diastolic paralysis, and that the organ commences to beat again when exposed to air. The arrest of the heart's action is due

to mechanical dilatation and the presence of an excess of carbonic acid.

The first and most constant symptom resulting from sudden and extensive embolism is a high degree of anæmia in all visible parts of the body. On post-mortem examination the white substance of the brain is completely bloodless, especially if small and numerous emboli have been injected. This general anæmia is followed by tetanic stretching of all extremities, involuntary discharges, and deep, convulsive, inspiratory movements. Ligature of both carotid arteries does not produce such an intense ischæmia of the brain. If the vertebral arteries are ligated at the same time, the tightening of the ligature of the second vertebral artery produces syncope and convulsions, but the symptoms are less intense than after sudden, fatal embolism of the pulmonary artery.

Panum also induced cerebral anæmia by injecting black pellets of wax, suspended in an emulsion, into the crural artery of a dog, throwing the injection in a central direction through a catheter which had been passed into the artery near the heart, producing thus multiple embolism in all of the smaller arteries. The animal lost only a few drops of blood, and no air entered. The animal was taken immediately with tetanic convulsions and involuntary discharges, and all organs accessible to the eye presented an extremely anæmic appearance. All reflex symptoms were arrested after one to two minutes. Two other experiments were followed by the same results. In all cases the small wax pellets were found in large numbers in the small vessels of the brain, as well as in all other parts of the body.

In four other dogs cerebral embolism was avoided by introducing the catheter only as high as the ribs, and by injecting slowly. During the injection a peculiar tremor was observed, which affected the muscles of the lower extremities; this, however, soon ceased, and gave way to complete paralysis of both motion and sensation, as well as complete arrest of all reflex movements. The first animal survived the experiment twenty-two hours, the second nine and a half hours, the third six hours, and the fourth five hours. The small vessels of the spinal cord were found obstructed by the small wax pellets, the vessels between the emboli and the heart were much dilated, and showed many small extravasations. The spinal cord was the seat of red softening, which was more conspicuous the longer

the life of the animal was prolonged. The spinal cord above the middle of the dorsal region and the brain were normal in appearance, although scattering pellets were found here also.

It will be seen that Panum, in contradistinction to Virchow, attributes the immediate cause of death in cases of rapidly fatal embolism to acute cerebral anæmia.

From a study of the literature on air-embolism, it is evident that the immediate cause of death has been assigned by different pathologists to one of the following conditions:

1. Mechanical dilatation of the heart and paralysis of the organ in the diastole.

2. Acute cerebral ischæmia.

3. Asphyxia, resulting from mechanical obstruction to the passage of the blood through the pulmonary circulation.

As we shall see further on, death from air-embolism is not always produced in the same manner; the mode of dying varies and is modified:

1. By the amount of air admitted.

2. By the time which has elapsed between the ingress of air and the fatal issue.

3. By the location and distribution of the emboli.

II. History of Air-Embolism.

Surgeons and pathologists have for a long time been aware of the deleterious effects of free atmospheric air in the vascular system. The danger attending the forcible insufflation of air into the veins of animals was well known to many of the earlier physiologists. Among the first to study the effects of the introduction of air into veins may be mentioned Redi, Wepfer, Camerarius, De Heyde, Harder, Bohnius, Boerhaave, Lancisi, Morgagni, Valsalva, Bichât, and Nysten.

As early as 1667 Redi killed animals by intravenous injections of air. He observed during his experiments that the pulse became intermittent, an occurrence which he attributed to the passage of a large air bubble through the heart. His followers who repeated the experiments, soon discovered that after forcible insufflation of air into veins the air became diffused, inasmuch as at the post-mortem examinations they found it present in the right auricle, the coronary vessels and, in the shape of air bubbles, in the smaller vessels.

Merg made the observation that on opening the abdomen of a dog and puncturing the vena cava above the origin of the emulgents, as the vein became emptied of blood it filled with air which ascended with the blood current and entered the right side of the heart. Haller witnessed the same phenomenon in cold-blooded animals after wounding some of the large venous trunks. He has shown that it was from this source that the air was derived which Redi, Caldesi, and Morgagni had seen circulating in the vessels of the same animals. He claimed that air is never seen in vessels when the necessary precautions are exercised to prevent its introduction through a wounded vein. Nysten found, by injecting air slowly into a vein, so as not to produce the death of the animal, that the coloring of the arterial blood was rendered imperfect. He satisfied himself that this change was not owing to the embarassment of respiration. Insufflation of oxygen had no effect in preventing or correcting this change of color in the arterial blood.

The literature on insufflation of air into veins is quite prolific and this subject cannot be justly passed over without an allusion to the following names which are intimately associated with the experimental part of the history of air-embolism:

Blochmann. Aër in venis causa mortis. Dresden, 1843.

Bouillaud. De l'introduction de l'air dans les veines. Paris, 1838.

Gain. De aëris ingressione in venas. Berlin, 1865.

Maguin. Etude expérimentale sur l'introduction forcée et sur l'entrée spontanée de l'air dans les veines. Nancy, 1879.

Méric. Recherches sur l'introduction de l'air et des gaz qui le constituent dans le système veineux. Paris, 1866.

Valkenhoff. De aëris in venas ingressu ejusque effectu lethali. 1840.

Laborde. Effets de l'introduction de l'air dans la circulation artérielle. Compt. Rend. Soc. de Biolog. Paris, 1873.

It was not long after the deleterious effects of free atmospheric air in the veins of animals had been studied experimentally before the same symptoms were observed in man by the accidental admission of air into wounded veins during operations, and in some of the first cases the presence of air in the veins and right side of the heart was demonstrated by post-mortem examination. Although a number of honest and reliable surgeons, prominent among them Velpeau and Fergusson,[1] have denied that a sufficient amount of air

[1] Lettre sur l'introduction de l'air dans les veines de l'homme. Gazette Médicale. Paris, 1838, pp. 113-121.

can be admitted through a wounded vein to produce sudden death, this assertion is no longer tenable in the face of such a large number of well-authenticated cases as have been recorded in surgical literature by equally conscientious and competent observers. Since the publication of the first well-authenticated case observed by Beauchêne and described by Magendie, the following authorities, placed in alphabetical order, have reported similar cases:

Amussat. Introduction de l'air dans les veines. Bulletin Acad. de Méd., Paris, i. pp. 894, 899, 1836; ii. pp. 363, 461, 1837–38.

Assmus. Zur Casuistik des Lufteindringens in grössere Venenstämme. Med. Zeitung, xi. p. 104. Berlin, 1842.

Barlow. An Attempt to remove a Tumor on the Neck; Entrance of Air in Vein; Sudden Death. Med.-Chir. Trans., xvi. pp. 28-35, 1830.

Chassaniol. Observation de l'entrée de l'air dans les veines pendant l'amputation du bras, dans son articulation scapulo-humérale. L'Union Médicale, viii. p. 428. Paris, 1869.

Clémot. Lanc. Franc., tom. i. p. 357, 1830.

Coolidge. Case of Sudden Death from Entrance of air into the Jugular Vein. New York Med. Gazette, i. p. 305, 1841-2. Also New York Med. Journal, vol. ix. pp. 199-201, 1847.

Cooper, B. Case of Alarming Syncope from the Admission of Air into a Vein, During Amputation of the Shoulder-Joint. The Lancet, i. pp. 448-451, 1843.

Cormack. Case of Death from the Entrance of Air by a Rigid Vein in the Neck, Opened Accidentally by a Seton-Needle. Lond. Med. Jour., 1850.

Delaporte. Extirpation l'une tumeur située au cou; introduction de l'air dans le système vasculair. Bulletin Acad. de Méd., i. p. 132. Paris, 1836.

Delpech. Mém. des hôpitaux du midi, No. 16, p. 231, 1830.

Fischer, H. Ueber die Gefahren des Lufteintritts in die Venen während einer Operation. Volkmann's Sammlung klin. Vorträge, Chirurgie. No. 34.

Gunn. Syncope from Entrance of Air into the Facial Vein. New York Medical Journal, p. 356, 1852.

Heckford. Four Cases of Entry of Air into the Circulation. Medical Times and Gazette, i. p. 137. London, 1867.

Koestlin. Ein Fall von Luft im Herzen. Med. Correspondenzblatt d. württ. ärztl. Ver., xxviii. pp. 316-321. Stuttgart, 1857.

De Lavacherie. De l'opportunité de l'extraction des tumeurs du cou non susceptibles de résolution; réflexions sur l'introduction de l'air dans le cœur par des veines ouvertes accidentellement. Mém. Acad. Roy. de Méd. de Belge, ii. pp. 305-376. Bruxelles, 1849.

McPharlin. Death from Entrance of Air into the Veins in a Case of Compound Fracture. Hosp. Gazette, iii. p. 20. New York, 1878.

Massart. Etude nouvelle sur l'entrée de l'air dans les veines, dans les cas de plaie ou d'opération chirurgicale. Annales Société de Médecine d'Anvers. xv. pp. 5, 57, 113, 1854.

Mercier. Journal des connaiss, p. 108, September, 1836.
Meyer, F. Case of Injury of the Vena Jugularis Interna; Entrance of Air; Sudden Collapse; Recovery. Med. Arch., iii. pp. 408-410. St. Louis, 1869.
Miner. Tumor in the Neck; Admission of Air into the Vein; Death. Buffalo Med. and Surg. Journal, pp. 336-338, 1864.
Mirault. Thèse. Paris, 1832.
Mott. Entrance of Air into the Facial Vein. Medico-Chir. Trans., 1830.
Piachaud. Mort par introduction de l'air dans une veine pendant l'ablation d'une tumeur du sein avec ganglions dans l'aisselle. Echo Médical, p. 768. Neuchâtel, 1857.
Porter. On the Entrance of Air into the Veins as a Cause of Death. Journal American Med. Assoc., iii. No. 20.
Rauch. Lufteintritt in einen verletzten grösseren Halsvenenast und seine Folgen. Oest. Med. Wochenschr., pp. 199-201. Wien, 1845.
Roux. Journal Hebdomadaire, ii. p. 64, 1833.
Schmid. Das Eindringen von Luft in eine Vene während einer Operation am Halse. Corresp. blatt d. württ. ärzt. Ver., xxi. p. 53. Stuttgart, 1851.
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Warren, J. M. Tumor Connected with the Sartorius Muscle; Secondary Cancer of Breast; Operation; Entrance of Air into the Vein; Recovery. Surgical Observations, p. 529. Boston, 1867.
Wattmann. Prager Vierteljahrsschrift, ii. p. 191, 1844.

This list is, of course, not complete, nor does it represent all the cases of accidental introduction of air during operations; but the names which are quoted ought to be accepted as sufficient guarantee by the most skeptical that the fear of this accident is not a myth, but a reality substantiated by many a sad experience.

III. Intravenous Production of Air.

Spontaneous production of air within the blood-vessels of recently deceased persons has been repeatedly observed, and to it has been assigned one of the causes of sudden death. That the air thus produced is a direct product from the blood appears to be negatived by the fact that its occurrence has usually been traced in

connection with sudden and exhaustive hæmorrhages. It is, in fact, in persons who have died from hæmorrhage, that air has been found in greatest abundance in the veins. Lieutand[1] reports the case of a girl who died suddenly in a state of syncope, after having been repeatedly bled, and in whom the cerebral veins and choroid plexus were found impacted with air. M. Rerolle[2] has published several cases of the kind, where profuse hæmorrhage had existed; in one of fatal epistaxis, the heart, arteries and veins contained large quantities of air. Dr. Graves has noticed emphysema of the abdominal parietes in a sufferer from repeated attacks of epistaxis. M. Rerolle conjectures that, in such cases, air is absorbed by the radicles of the pulmonary veins—the air would have no claim to be considered adventitious.[3]

It is, however, more logical to assume that, as in almost all cases the supposed intravenous origin of air took place after severe loss of blood together with loss of continuity of the vascular system, owing to the sudden loss of intravascular pressure, the air may have been aspirated through the openings of some of the bleeding vessels. The quantity of air found in these cases has been so small that it has been impossible to make a chemical examination to determine its identity with atmospheric air. In cases where air was found in blood without loss of continuity of the vessels, it is not impossible that the supposed air was not atmospheric air, but a gaseous product liberated from the blood or generated in the tissues, producing a gas-embolism which interfered with the function of circulation in a similar manner as when the obstruction was caused by atmospheric air.

IV. Effect of the Heart and Respiration on the Venous Circulation.

As the state of the intravenous blood pressure constitutes the most important element both in the prevention and causation of aspiration of air into veins, this subject must be briefly alluded to in order to determine the conditions which act as exciting causes. For the most reliable and comprehensive information on this subject we

[1] Hist. Anat., Med. Obs. 55.

[2] Thèse de Paris, No. 129, 1832.

[3] Todd's Cyclopædia of Anat. and Physiol., vol. iv. part i, p. 145.

are indebted to Dr. Heinrich Jacobson.[1] The observations were made on sheep. To determine the effect of the heart's action upon the venous circulation he measured the blood pressure in veins with the manometer. These measurements were made on veins in close proximity to the heart, as the lower portion of the jugular and subclavian, as all attempts to approach nearer the heart seriously impaired the normal physiological conditions of the respiratory and circulatory organs. This measurement gave the following results:

In the left vena anonyma	—0.1 mm. Hg.
" " right " jugularis	+0.2 " "
" " right " subclavia	—0.1 " "
" " left " jugularis	—0.1 " "
" " left " subclavia	—0.6 " "

The following are his observations on some of the more distal veins in the same animal:

In the external facial vein	+3.0 mm. Hg.
" " internal " "	+5.2 " "
" " brachial vein	+4.1 " "
" a branch of the brachial	+9.0 " "
" the crural vein	+11.4 " "

The experiments of Ludwig and Mogk, although made in a similar manner, led to more variable and inconstant results; at one time they found the blood-pressure in the crural vein 6.8 mm. Hg., while on another occasion under similar circumstances it measured in the same vein only 1.9 mm. Hg. Donders explains this want of uniformity by the respiratory movements of the chest, believing that the aspiratory movements of the chest affect the venous circulation more than the *vis a tergo* from the capillary system.

Poisenille claimed that in his experiments the manometer was affected by the respiratory movements of the chest only when it was inserted into veins in close proximity to the heart, as in the lower portion of the jugular and the external iliac veins, while in more distant veins the column of mercury was not affected by the movements of the chest. Volkmann obtained the following measurements:

In the facial vein of a goat	41 mm. Hg.
" " jugular vein of a goat	18 " "
" " metatarsal vein of a calf	27 " "
" " jugular vein of a calf	21.5 " "
" a subcutaneous vein of the neck of a horse	44 " "
" the jugular vein of a horse	21.5 " "

[1] Ueber Blutbewegung in den Venen. Virchow's Archiv, xxxvi. p. 80.

Magendie found the blood-pressure in the external jugular vein of a dog 18 mm. Hg., and in the crural vein 50 mm. Hg. Although the measurements of the intravenous blood-pressure taken by different observers are at great variance, and although their figures are indicative of the opinions held by the different experimenters as to the effect of respiration upon the return of venous blood, yet they all agree in locating the minimum degree of intravenous pressure in the veins nearest the heart.

The effect of respiration on the venous circulation was thoroughly investigated by Magendie. He introduced an elastic tube into the internal jugular vein, and observed that blood would escape only during expiration. The same experiment was made on the crural vein by directing the tube toward the heart, and was followed by the same result. The suction force exerted during inspiration was sufficient to counter-balance the auricular contractions. In making these experiments air was frequently drawn into the heart during forcible inspiration. Barry introduced through the jugular vein of a horse a bent tube of glass, one extremity being passed into the right cavity of the heart, or the vena cava, and the other into a vessel containing a colored fluid. He found that with each act of inspiration the liquid rose in the tube, demonstrating the effect of a notable suction force. He found that this suction force was increased by preventing the entrance of the air into the chest through the trachea. He was of the opinion that this force from the chest was exerted not only in the large veins near the heart, but throughout the entire venous system.

Schweinburg[1] has studied the effect of respiration on the circulation by producing paralysis of the diaphragm by section of the phrenic nerves. He states that when diaphragmatic respiration has been artificially arrested, the difference of blood pressure observed during respiration entirely or nearly ceases. From this he concludes that the action of the diaphragm causes to a certain extent these differences. Even after opening the abdominal cavity the difference in blood-pressure is very slight. He considers the compression of the abdominal vessels during inspiration as the principal cause in abolishing the effect of respiration upon the circulation.

[1] Die Bedeutung der Zwerchfellcontractionen für die respirat. Blutschwankungen. Du Bois-Reymond's Archiv, 1881, p. 475.

causing the increase of blood pressure during inspiration and its diminution during expiration by diminishing intra-abdominal compression. If the jugular vein in an animal is exposed, direct observations show conclusively that the direct influence of inspiration cannot be felt much beyond these vessels. The flaccidity of the walls of the veins will not permit the extended action of any suction force, but the flow of blood in the distant veins is accelerated by the intermittent emptying of the veins by the respiratory act. Barry and Donders ascribe to the aspiratory function of the chest, the principal motor in the return of the venous blood. Donders estimated the aspiratory force of the inspiratory movements of the chest at 7 mm. Hg.

Clinical observation and experimental research have established the fact that the venous circulation is directly influenced by respiration within a certain area, and that aspiration of air in the majority of cases takes place in those veins so affected, thus constituting the justly much dreaded "danger-zone." Instead of speaking of the effect of respiration on the veins as a cause of aspiration of air, some authors speak of the vein pulse, and limit the danger-zone to the veins which pulsate. Under certain circumstances the pulsations of the arteries are communicated directly to the veins through the capillaries. In such instances it is necessary that the arterioles be relaxed, as has been ascertained by Bernard in observing the circulation in glands during their physiological activity. If a vein be opened in a gland during its physiological activity, the blood partly retains its arterial hue and escapes in intermittent jets, as from a divided artery. According to recent physiological investigations, veins continue to pulsate independently of the arterial system and the cerebro-spinal centers.

Luchsinger[1] examined the venous pulsation in the wings of bats. Contrary to Schiff's observations he found it independent of the central nervous system. Division of the brachial plexus and separation of all tissue connections between hand and body, with the exception of the vessels, did not arrest it. If artificial circulation was established in the organ after amputation, rhythmic venous contractions would be seen even twenty hours after death. Intraven-

[1] Von den Venenherzen in der Flughaut der Fledermäuse. Pflüger's Archiv, 1881, vol. xxvi.

ous pressure was found to be of great importance in these experiments; as soon as it was increased the vein began to pulsate. The seat of these rhythmic contractions Luchsinger placed in the walls of the vessels, or rather in their muscular structures. They were probably regulated by the central nervous system. Slight increase of warmth and electric tetanization accelerated the contractions. High temperature caused diastolic stasis. Nitrite of amyl increased the pulsating only to arrest it later. Schiff has since satisfied himself that these pulsations continue after division of the brachial plexus and ligature of the vessels, and even in the veins in detached pieces of the bat's wings.

Brunton[1] has made the same observations on man in regard to the effect of increased intravascular pressure in producing venous pulsations in the larger veins. He finds that pulsation of the jugular vein is sometimes confined to one side, the left one. In one of his cases the jugular on the left side was much more distended than the right jugular, the distention increasing whenever the vein was compressed just above the clavicle. Whenever this compression was repeated in the rhythm of the pulse, the increase and decrease of the blood in the vein assumed the character of pulsation, and for this reason the author has arrived at the conclusion that the venous pulsation in such cases is caused by compression of the vena anonyma by the aorta. All cases of unilateral jugular pulsation observed by Brunton occurred in anæmic women. In one of these the pulsation took place only while the patient was affected by some emotional excitement, in another only during expiration.

In rabbits the author has repeatedly observed rhythmical contractions of the pulmonary veins, the vena cava inferior, and the portal vein, occurring immediately after the death of the animals. These pulsations were present after complete cessation of the heart's action, and sometimes even before death, and, as the pulsations were more frequent than the heart's action, it was plain that they occurred independently of any contraction of that organ. In consequence of long-continued pressure on a vein the author has seen tonic contractions take place, especially in smaller veins, and this may explain the cause of some of the irregularities of the circulation and subsequent transudation.

[1] On Pulsations in the Jugulars and other Veins. Medical Press and Circular, July 2, 1879.

Riegel[1] has made vein pulsation a special subject of investigation, and as a result of his researches he has come to the following conclusions: 1. There exists in the normal condition, a pulsation of the jugular vein. 2. This normal pulsation is always anadicrotic, that is, its wave rises in two distinct intervals. The anadicrotic wave corresponds, in contradistinction to the pulsation of the carotids, to the diastole of the heart. The short catacrotic line or wave corresponds to the systole, the anacrotic, to the diastole of the heart. Synchronously with the systole, the contents of the vein are emptied into the heart, while during the diastole, stasis takes place in the veins.

King,[2] in his interesting essay "On the Safety-Valve Function in the Right Ventricle of the Human Heart," demonstrates the existence of venous pulsations in the veins of the hand, the median veins of the forehead, and the external jugular, which he observed after a full meal. The pulsations were made plainly visible by taking a delicate thread of sealing wax about two inches in length, one end of which was fixed across the vein with a little tallow so as to make a long and excessively light lever, capable of indicating a very slight movement in the vessel. The movements of the lever produced by the vein pulse corresponded in frequency with the pulsations of the arteries in the same vicinity, but did not correspond in time, as the venous pulse followed the arterial systole, showing conclusively that it was not due to the impulse of an adjacent artery. The pulsations could only be caused by the arterial wave being continued to the veins through the capillary vessels. In certain pathological conditions independently of valvular lesion of the heart, he noted a marked increase in the venous pulsations in the dorsal veins of the hand and other vessels distant from the heart.

The subject of the vein pulse affords an interesting topic in physiology, but in connection with this paper it is only mentioned in order to show that the intravenous tension is only slightly affected by it, and that consequently it can exert no direct influence in causing aspiration of air into veins. The venous pulsations which directly influence the return of the venous blood to the right side of the heart occur synchronously with the movements of respiration,

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[1] Zur Kenntniss von dem Verhalten des Venensystems unter normalen und pathologischen Verhältnissen. Berl. Klin. Wochenschrift, No. 18, 1881.

[2] Guy's Hospital Reports, 1837, p. 108.

and are observed only in the veins which are in close proximity to the heart, and in venous channels with firm unyielding walls. The introduction of air can only follow in wounds of vessels where the intravascular pressure is subjected to great variations, either from normal anatomico-physiological conditions, or as the result of pathological alterations. All causes which prevent a prompt collapse of the walls of a wounded vein must be considered as predisposing causes, while all conditions which tend to produce a vacuum in the wounded vein act as determining causes. The location of the former corresponds to the point of injury, while the latter are always represented by the aspiratory action of the chest during inspiration.

V. Aspiration of Air into the Superior Longitudinal Sinus.

Nearly all of the older physiologists were of the opinion that aspiration of air into veins could only take place in vessels which were in close proximity to the heart and within reach of the venous pulse. Mery claimed that the effect of thoracic aspiration on the venous circulation extended to the sinuses of the dura mater and venous channels in the diploë of the cranial bones. Bernard was aware that air might enter the sinuses in case these structures were wounded, as this accident ocurred a number of times in his experiments on animals where the superior longitudinal sinus was opened for other purposes. He believed that the air, after entering the sinus, reaches the heart through the vertebral veins and the vena azygos. Death in such instances took place in eighteen minutes, while forty-five minutes were required if death resulted from hæmorrhage alone.

Volkmann's case, reported in another part of this paper, demonstrates to a certainty that death may be caused by the entrance of air through a wound of the longitudinal sinus. Although this is the only authenticated case on record, similar cases have undoubtedly occurred before, but the real cause of death was not recognized, and the fatal result was attributed to some other source. This subject of aspiration of air into the longitudinal sinus was made the object of experimental inquiry by Genzmer, one of Volkmann's assistants.[1]

[1] Extirpation eines faustgrossen Fungus duræ matris, tödtlich verlaufen durch Lufteintritt in den geöffneten Sinus longitudinalis. Verh. d. deutschen Gesellschaft f. Chirurgie, vol. vi. p. 32.

The experiments were made on dogs, as this vessel in rabbits was found too small for the operation. Nine experiments were made. The animals were made partially insensible by morphine injections. The skull was exposed by an incision which was carried from the occipital bone to the forehead; with a small straight chisel, a section of bone about 6 cm. square was mapped out by cutting through the external table, anteriorly to the prominentia occipitalis externa, and was completely detached with a hollow chisel. The dura mater having thus been freely exposed, the posterior portion of the longitudinal sinus, which was about 2 mm. in width, was made accessible about its middle. The sinus was made tense and divided transversely between two small hooks, carefully guarding against injury to the subarachnoidean space.

In some of the experiments the wound was kept patent by making traction on its margins with the hooks, in others this precaution was unnecessary as the edges of the wound retracted sufficiently to keep it open. For several minutes after incision the bleeding continued profusely; the blood was quite red and escaped with some degree of force, the pulsations being plainly visible and synchronous with the heart's action. The stream was also perceptibly increased and diminished by the respiratory movements of the chest. After a few minutes had elapsed the hæmorrhage became less profuse. In case the animal died, the heart and lungs were removed, after carefully tying the large vessels so as to prevent the escape of air from the heart.

To secure accuracy in ascertaining the presence of air in the heart, this organ was opened under water, when the rising bubbles would indicate its presence. In two of these cases the animal breathed through a tracheal cannula, the double rhythm in the blood column was lost soon after the sinus was opened, and the blood continued to flow until the death of the animal, which occurred after thirty-five, forty, and fifty-three minutes, respectively, the stream from the peripheral end of the sinus growing constantly less during this time. In all of these cases the central end of the sinus was completely filled with a thrombus, and no air was found in the heart. In two other cases the double rhythm continued until life was extinct, which was the case after twelve and nineteen minutes. After the first two or three minutes the bleeding diminished, and, by removing the blood from time to time with a sponge, it could be seen how air

was aspirated during inspiration through the gaping wound. During forcible expiration, or on compressing the chest, air bubbles escaped with the blood from the wound, from the proximal end of the sinus. As the bleeding diminished, air aspiration became more copious and more frequent.

An examination of the cadavers of these animals revealed that the right side of the heart contained air and spumous blood. In the next two cases artificial dyspnœa was produced, in one instance by dividing both pneumogastric nerves, in the other by closing the tracheal cannula through which the animal was breathing. In the first case air entered early and the animal died in sixteen minutes; in the second case air entered freely during the forcible inspiratory efforts and the animal died in twenty-four minutes. In both of these cases air was found in the right side of the heart and in the subpleural vessels. In the last two experiments the animals were killed fifteen and sixty minutes after the sinus was opened, by puncturing the brain with a needle. In the first case a considerable amount of air was found in the right side of the heart, and in the second case the amount of air contained in the right side of the heart was less, the apparent difference being due to the presence of a thrombus in the central end of the sinus in this case, which prevented further ingress of air.

In recapitulation it may be stated that in six out of nine experiments, air entered the longitudinal sinus, thus proving conclusively that wounds of this great reservoir of venous blood are not only dangerous from the loss of blood, thrombosis, and inflammation, but may also become the direct cause of sudden death by admitting air into the venous circulation.

VI. Experiments.

These experiments were made by the writer for the purpose of ascertaining more fully the conditions which determine the entrance of air into a wounded longitudinal sinus, and, at the same time, in order to obtain reliable information concerning the prophylactic measures as well as to determine the best methods of arresting hæmorrhage in wounds of this vessel. All operations were made under antiseptic precautions; when not specified no anæsthetic was used. The field of operation was cleanly shaved, and the surface thoroughly

disinfected with a five per cent. solution of carbolic acid; during the operations, frequent use was made of the irrigator, using a warm two per cent. solution of the same antiseptic. When the animal survived the operation, the wound was closed with continued catgut sutures, and dressed with iodoform and a compress of salicylated cotton retained by a roller bandage.

The operation consisted in making a longitudinal incision in the median line of the skull, reaching from the external occipital protuberance to near the upper extremity of the frontal sinuses. The soft parts with the periosteum were separated and reflected on each side, so as to lay bare the bone over a sufficiently large area for the ready use of the bone-cutting instruments. A medium-sized trephine was applied over the middle of the longitudinal sinus, and the button of bone carefully removed so as to prevent injury of the underlying vessel. The enlargement of the circular aperture was effected with a hollow chisel and Luer's bone-forceps. The opening in the bone was made of an oval or oblong shape with the longest diameter parallel to the sinus, in order to bring into view a large extent of the vessel with a minimum destruction of the cranial vault.

Experiment 1. Small Skye terrier, weight twelve pounds. Ether used as an anæsthetic. Longitudinal sinus laid bare to the extent of one and one-half inches by an oval opening in the skull. Copious hæmorrhage from a vein leading into sinus, which was arrested after ligature. Two catgut ligatures were placed underneath the sinus, about half an inch apart, and the vessel cut transversely between them. The bleeding was very copious, the blood escaping in jets synchronous with the heart's impulse; the flow was also distinctly increased and diminished by the respiratory movements of the chest. During inspiration the stream was diminished, while expiration was always attended by a decided increase in the force of the jet and the amount of bleeding. No air was seen to enter, although the hæmorrhage had been very profuse and continuous for a considerable length of time.

As it was intended by this experiment to prove that sudden obliteration of the longitudinal sinus is not incompatible with life, the distal ligature was tied with the effect of nearly but not completely arresting the hæmorrhage, as some blood escaped from the proximal end of the vessel. It was now expected that air would be more prone to enter through the gaping wound in the sinus, as the blood pressure from the distal end of the vessel had been arrested by the ligature, but as this accident did not take place after a few minutes the second ligature was tied, and the wound in the skin united with the continued catgut suture, and the antiseptic compress applied. The animal showed no other symptoms except great prostration from the sudden and profuse loss of blood. After an hour it rallied and apparently was in full possession of all its

special senses, and was able to walk about as usual. The next day it manifested a ravenous appetite, and, during the whole time it was kept under observation, it showed no signs of illness or discomfort. The wound united by primary union, the skull showing the oblong bony defect at the site of the operation, through which the pulsations of the brain could be distinctly seen and felt. Unfortunately the animal ran away after complete recovery had taken place, and deprived me of the opportunity to study by post-mortem examination the local effect on the intracranial circulation by the operation.

This experiment tends to prove that ligature of the longitudinal sinus can be performed without seriously compromising the functions of the brain, and that in certain well-defined instances, this procedure might be resorted to in practice with a view of preventing or arresting hæmorrhage from, and the entrance of air into, this vessel, in intentional or accidental wounds of the sinus.

Experiment 2. Small tan cur, weight ten pounds. Partial ether anæsthesia. Longitudinal sinus opened by two transverse incisions in close proximity; hæmorrhage alarming, at first in jets, and, as the bleeding diminished, in a more continuous flow. At first the blood was bright red, but as respiration became impaired, it grew darker in color. Dilating forceps were introduced into the proximal wound, the hæmorrhage continued, but no air entered as long as the animal was in a lying position. As the respiration became more irregular and superficial, artificial respiration was resorted to, and the head placed in an elevated position, whereupon the heart suddenly ceased to pulsate, and, upon applying the ear to the precordial region, a few irregular and very feeble contractions were heard, attended by a distinct churning sound, when the animal suddenly expired.

Before death, electricity was used with the effect of improving the respirations, but it had no effect whatever upon the action of the heart. Death took place about three-quarters of an hour after the sinus was opened. At the examination, immediately after death, all the tissues and organs were found in an exsanguinated condition. All the vessels leading to and from the heart were carefully tied, and the organ removed. On being placed in water it floated like a cork; the right auricle and ventricle were dilated, and on being opened under water, bubbles of air and only a very slight amount of spumous blood escaped. The pulmonary artery was also distended with air. The left ventricle was almost completely empty.

In this instance the animal almost bled to death from the wounds in the longitudinal sinus, and yet no air entered, although the wound was kept patent with a pair of forceps. The entrance of air was caused by the elevation of the head and the forcible movements of the chest during the performance of artificial respiration. To judge from the amount of air found in the right side of the heart and its effects, the air must have entered quickly and in considerable quantity, distending at once the right side of the heart to such an extent as to paralyze the muscles of the heart in the diastole, after a few feeble attempts to force it from the right chambers. I believe, if the animal had been left in the lying position, and the head dependent, that death would have

taken place from hæmorrhage, as the blood which was draining through the sinus prevented the entrance of air. As soon as the head was raised, however, the contents of the sinus flowed by gravitation towards the heart, and air entered with it to fill the vacuum which was being prepared by the diminished blood supply to the brain, and the acceleration of venous return, as well as the increased aspiration of the chest, which was brought about by the attempts at artificial respiration.

Experiment 3. Horse, about twelve years old. Partial chloroform anæsthesia. Animal kept lying on the ground, the head on a level with the body. Longitudinal sinus exposed for about two inches and a longitudinal incision one inch in length made. Hæmorrhage very profuse; blood at first bright red, gradually growing darker in color; double wave well marked. After about three quarts of blood had been lost, as the hæmorrhage still continued at the same rate, and was not readily controlled by the ordinary compression, it was decided to implant an aseptic sponge into the sinus. This was done, and the external wound united over it by the continuous suture. No air was seen to enter the wound, and auscultation over the heart revealed no abnormal sounds. During the operation of chiselling, the apices of the frontal sinuses were opened, which led to the fear that infection of the wound would subsequently take place from this source. This expectation was realized. The animal rallied soon after the operation, and appeared to be quite well for three days subsequently, grazing in the pasture with other horses. On the morning of the fourth day it was found dead.

Examination of the cadaver showed that the proximal end of the sinus was closed by a thrombus firmly adherent to the walls of the vessels and the implanted sponge, but about the distal end of the sponge, at a point which corresponded to the opening in the frontal sinuses, the brain and meninges showed all the appearances of acute septic inflammation. If infection had not taken place the aseptic sponge would have fulfilled all the purposes for which it was intended—arrest of hæmorrhage and obliteration of the sinus. It seems to me that in cases of uncontrollable hæmorrhage from accessible venous sinuses, the implantation of an aseptic sponge would prove a safe and efficient measure against hæmorrhage, and would offer no obstacle to primary union and definitive closure of the vessel, as during the process of granulation the sponge would disappear by absorption.

Experiment 4. Horse, fourteen years old, in good condition. This experiment was made for the purpose of confirming the suspicions already gained that the force of gravitation constitutes the most important factor in determining the admission of air into an open sinus of the dura mater; consequently no anæsthetic was given, but the animal was firmly held by a bit, and the operation was performed, without any difficulty, while the animal was in a standing position with the head elevated. With the trephine and chisel an oval opening, about two and a half inches in extent, was made over the longitudinal sinus. After all oozing had ceased, the sinus being fully in view, its anterior wall was divided completely in a transverse direction. The edges of the wound immediately retracted, forming a diamond-shaped opening through

which blood escaped in moderate force, but not nearly as copiously as on previous occasions when the animals were in the lying position.

During the first inspiration after incision air entered with a loud gurgling or lapping sound, and on applying the ear over the apex of the heart, a loud churning sound was heard synchronous with the movements of the heart. During expiration air-bubbles were seen to escape from the proximal end of the sinus. As soon as the head was depressed the hæmorrhage greatly increased, but air never entered in this position; as soon as the head was elevated, however, hæmorrhage either ceased entirely or was at least greatly diminished, but air was sure to enter during inspiration. These manœuvres were repeated a number of times, and always with the same results. As the amount of air which was aspirated increased, the respirations became more labored, and signs of cyanosis became apparent. An attempt was now made to close the wound in the sinus by sutures, and in this way arrest the hæmorrhage. Three catgut sutures were passed through both edges of the wound, bnt on attempting to approximate its margins every one of them tore through the tissues before the parts were in apposition, proving conclusively that transverse wounds of the longitudinal sinus cannot be sntured, owing to the unyielding nature of the tissues. The external wonnd was completely closed by the continuous suture, and a firm graduated antiseptic compress controlled the bleeding.

During the whole time of the operation, which lasted over an honr, some one of the bystanders listened to the heart's action, and the loud splashing or churning sounds were constantly heard. When the animal was released it commenced grazing in the pasture, and appeared as well as before the operation. The heart was examined at intervals of thirty minutes, and the abnormal sounds grew more feeble, and after an hour had entirely disappeared. The sound produced by the entering air, I have described as lapping, resembling very much the sound produced by the lapping of a dog or cat; the best possible word for this sound is the German expression "schluerfend." When air enters through a wound of the longitudinal sinus this sound is characteristic, and is always the same, and, in case the animal operated upon is a horse. it is sufficiently loud to be heard at some distance.

Experiments have shown that horses are most tolerant to the presence of air in veins, on account of the unusual development of the right ventricle, which has sufficient power to force the air through the pulmonary circulation. This experiment would certainly tend to corroborate this observation, as air in large quantities was aspirated at least a dozen times during the operation. That most of it entered the right side of the heart, and was not returned is evident from the persistence of the sounds, due to the presence of air for a period of two hours; and yet, aside from a certain degree of embarrassment of respiration, the animal suffered no inconvenience.

The wound healed by primary union. The defect in the skull remained permanent. The animal was killed about four weeks afterwards. Post-mortem appearances: The trephine opening filled with cicatricial tissue. Proximal end of sinus, just behind trephine opening, contained one large granulation

thrombus. Cicatricial tissue filled almost the entire lumen of the sinus. Anteriorly the sinus was somewhat contracted and smooth; no thrombus here or evidences of proliferation. The circulation was apparently restored by the formation of a new channel, or dilatation of a pre-existing one; this new sinus was located to the left of the median line. The lateral sinuses were very much enlarged.

Experiment 5. Young yellow dog, weight about fifteen pounds. Partial ether anæsthesia. Longitudinal sinus exposed and transversely incised at two points in close proximity. The hæmorrhage, which was profuse, was allowed to continue for over half an hour in order to estimate the length of time which would be necessary for death to occur from this cause uncomplicated by admission of air. When the animal appeared moribund both ends of the sinus were ligated. The heart's action was very feeble and irregular, while respiration was entirely suspended. Artificial respiration was kept up until the heart's action ceased. Death occurred in thirty-five minutes. At the examination after death, no air was found in the vessels or heart, and death was plainly attributable in the absence of any other cause, solely to the loss of blood.

Experiment 6. Newfoundland dog, weight fifty pounds. Partial ether narcosis. During the removal of bone over the sinus, severe hæmorrhage was encountered from the large venous channels in the diploë. The great irregularity of the external surface of the skull led to a mistake, as the frontal sinuses were again opened. The longitudinal sinus was laid open by an incision half an inch in length in a direction parallel to the vessel. Hæmorrhage very profuse for half an hour, checked at times by compression, when it finally diminished and the wound was closed. After the operation the animal walked with a staggering gait, and would run against objects indiscriminately, showing that sight was greatly impaired, inasmuch as the animal had fully recovered from the effects of the ether. No air was seen or heard to enter the sinus. Heart sounds feeble, but otherwise normal. Death in this case took place a week after the operation from lepto-meningitis. The source of infection undoubtedly was again traceable to injury of the frontal sinus, as the earliest evidences of the disease were found nearest the opening in this structure.

Experiment 7. Old decrepit horse. Operation was performed while the animal was in the erect position. On removing disc with the trephine a longitudinal wound one-half inch in length was found in the anterior wall of the sinus, through which bright red blood escaped. Double pulsation well marked. Almost immediately after the removal of the disc of bone, and before more than an ounce of blood had escaped, air entered with a loud and distinct lapping sound, audible to all who were present. On applying the ear over the heart the same loud churning sounds were heard. As the head was lowered the flow of blood became more forcible and copious, but no air entered; as soon, however, as the head was elevated, bleeding diminished, and air entered during almost every inspiration. Respiration became labored,

and after air had entered four or five different times in succession, the animal fell to the ground.

In this position no further entrance of air occurred, but the hæmorrhage continued copiously, the blood flowing in a continuous stream with a well-marked double jet synchronous with the action of the heart and the respiratory movements of the chest. The opening in the skull was enlarged to two inches in length and one and one-half inches in width, so as to expose the sinus freely. A number of catgut sutures were now introduced through both lips of the wound, and on attempting to tie them great difficulty was experienced in approximating its margins, which could not be brought completely in contact without the sutures tearing through. The tying of all the sutures resulted in diminishing but not arresting the bleeding, showing conclusively that in longitudinal wounds of the sinus, suturing is an imperfect and unreliable measure in arresting hæmorrhage, to say nothing of the difficulty which is experienced in passing the sutures at such great depths and in the limited space furnished by the artificial opening in the skull.

The wound was not closed but tamponed with iodoform cotton in order to observe from time to time the processes which nature would initiate in the restoration of the wounded sinus. Half an hour after the first entrance of air the churning sounds in the heart had much diminished, and almost completely disappeared after the lapse of one hour. The animal recovered completely from the immediate effects of the air-embolism, the respiration having again become normal in frequency and character. After two hours the tampon was removed, but bleeding again occurred, and it was replaced. The animal died twenty-four hours after the operation, probably from the combined effect of loss of blood, hæmorrhage into the subdural spaces, air-embolism and senile marasmus. At the examination of the cadaver a subdural clot, which weighed about half an ounce, was found on the right side of the brain; on the left side of the sinus a second but smaller subdural clot was found. Trephine opening filled by a coagulum. One of the sutures had lost its hold by tearing through the tissues of one margin of the wound. Within the sinus a small fragile clot was found in the lateral wall of the sinus which served as the source of hæmorrhage into the subdural space.

This experiment well illustrates the danger of plugging the opening in the skull for the purpose of arresting hæmorrhage in case the lateral walls of the sinus are injured, as it will almost necessarily lead to subdural hæmorrhage, and expose the patient to all the disastrous consequences incident to this occurrence. In this instance sponge implantation would not only have more successfully guarded against external bleeding, but would also have served as a sure prophylactic against extravasation into the subdural space. It also teaches that suturing in cases of wounds of the longitudinal sinus with limited defects in the bony walls of the cranium is impracticable, unreliable, and unsafe, and should never be resorted to unless the dura mater is so extensively exposed or separated as to permit, by making gentle traction, perfect and complete approximation of the margins of the wound.

VII. Practical Suggestions.

In order to study the conditions which favor the aspiration of air into a wounded sinus of the brain it is necessary to call attention to some of the peculiarities of the intra-cranial circulation. Mosso,[1] who has made this a special subject of investigation, asserts that the intravascular pressure in the veins within the cranium is higher than in the veins of any other part of the body. Actual measurements have shown that the blood-pressure in the longitudinal sinus is equal to 100-110 mm. Hg. The probable cause of this phenomenon is that the force of distention of the arteries within the closed and unyielding cranial cavity is added to the *vis a tergo*. The intra-cranial veins show distinct pulsations which are dependent upon the pulsations of the arteries, and their movements are so plain that they can be graphically demonstrated; every diastolic movement in the artery corresponds to a venous pulse. During the pulsations of the brain, Mosso claims with Donders and Berlin, that the cerebro-spinal fluid does not escape into the spinal canal. In a case of spina bifida he has been able to trace respiratory but no circulatory movements. When the tumor was compressed only a very slight increase in the volume of the brain could be detected at the fontanelle, even if nearly the whole contents of the tumor were pressed into the spinal canal.

G. Burkhart[2] has published the results of his observations on the movements of the brain which he made on four patients who had suffered partial loss of the cranial vault. The tracings obtained represented three forms of movements—pulsatile, respiratory, and vascular. The cerebral pulsation has the form of a tricrotic or tetracrotic pulse, the phases following one another in about the same time as those of the carotid pulse. His observations lead him to the conclusion that the brain presents the same movements within the intact skull as in the infant or when a defect in the skull exists, the result of traumatism. The brain expansion is synchronous with the dilatation of the vessels and takes place in the direction of the vascular ramifications. The resistance is in inverse proportion to this expansion.

In the closed skull the excess of pressure in the arteries materi-

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[1] Ueber den Kreislauf des Blutes im menschlichen Gehirn, 1881.

[2] The Lancet, Oct. 15, 1881.

ally aids the propulsion of the blood through the veins, and also that of the sero-lymphatic fluid. In the open skull the curve rises during expiration and falls during inspiration. All actions which increase the respiratory movements increase the height of the curve. A secondary elevation follows labored inspiratory movements, but the pulse waves are never completely effaced. The vascular curves occur independently of respiration or pulsation. The height of the curves bears no constant relation to their length. They are notably affected by psychical influences. They are produced by movements of the vessels by means of the vaso-motor nerves, and can be made very conspicuous by irritation of the cervical sympathetic.

Bergmann,[1] in his remarks on the movements of the brain (in opposition to Mosso) at the meeting of the Congress of German Surgeons in 1881, insisted that the cerebro-spinal fluid acts as a regulator in maintaining the equilibrium between the arterial and venous circulation within the cranium. The pulsations of the sinuses of the dura mater were discovered and studied under his supervision at Dorpat as early as 1873. He argues that these pulsations are very slight, and on that account insufficient to counterbalance the arterial pulsations. He explains the pulsations of the sinuses in the same way that Donders and Jacobi have accounted for the pulsations in the veins of the papilla of the optic nerve. The pulsations are the result of increased tension in the cerebro-spinal fluid during the arterial systole, and the consecutive diminution of intracranial pressure during the arterial diastole.

The cranium being a closed cavity with unyielding walls, it is not difficult to understand that in case one of the sinuses is opened by a wound which communicates with the atmospheric air, the sudden loss of blood will have a tendency to create a vacuum which is filled by the admission of air which reaches the left side of the heart with the venous blood. All circumstances which diminish intravascular and intracranial pressure must of necessity favor the occurrence of aspiration of air into a wounded sinus. It is evident that aspiration of air into an open wound of the longitudinal or any other sinus of the dura mater is favored by the following conditions: 1. The force of gravitation. 2. The inspiratory movements of the chest. 3. The condition of arterial circulation. In considering the

[1] Verhandlungen d. deutschen Gesellschaft f. Chirurgie, vol. x. p. 14.

prophylactic treatment against the admission of air during operations which involve any of the cerebral sinuses, it is of the greatest importance to keep the head at a level with the heart to insure regular respiration and to guard against undue or forcible inspiration, and, finally, to maintain the normal activity of the ventricular contractions. The direct preventive measures consist in: 1. Continuous irrigation of the field of operation. 2. Prophylactic ligation of the sinus.

In resorting to constant irrigation the fluid used should be an aseptic solution at the temperature of the body, which, if it should enter the venous circulation to fill an empty space, would do no harm either as a toxic agent or by causing coagulation of the blood. A solution of salicylic acid in distilled water, or borated water would be best adapted for this purpose. In extirpating tumors of the dura mater in the region of the longitudinal sinus, where wounding of this structure becomes a necessity, it would not only be prudent but good practice to ligate the sinus on each side before attempting the removal of the tumor, as this precaution would surely and effectually prevent the two most dangerous and alarming accidents—hæmorrhage and aspiration of air. This plan was followed by Kuester in removing a sarcoma of the dura mater in 1881.[1]

Experiments on animals and the cadaver have convinced me that this operation can be performed with comparative ease, if the defect in the skull is sufficient in extent to permit the necessary manipulations, and, in the event this operation be done for the purpose of facilitating the removal of tumors of the dura mater, this precaution should never be neglected. With a tenaculum the dura mater should be seized and drawn forward at the outer border of the longitudinal sinus, and a small incision parallel with the border of the sinus made with a tenotome, the incision being only sufficiently deep to divide the dura mater. After making such incisions on each side of the sinus directly opposite each other, the sinus should be grasped with a sharp-toothed spring-forceps and drawn forward, a small curved sharp-pointed aneurism needle passed into one of the openings, and, after penetrating the falx cerebri underneath the vessel, brought out through the opening on the opposite side.

[1] Berl. Klin. Wochenschrift, 1881, p. 673.

When both of the ligatures are in place the peripheral ligature is tied first, and after emptying the intervening part of the vessel of its contents, the proximal ligature is also tied. If both of the ligatures have been properly applied, the intervening portion of the sinus can be opened or excised with the tumor without risk of hæmorrhage or the introduction of air; at the same time it will greatly facilitate thoroughness in the removal of diseased tissue. I am firmly convinced that the preliminary ligation of the longitudinal sinus will become an established procedure in all cases where tumors of the dura mater are so situated that their removal implicates this structure, and that it will render possible the removal of tumors which without it would place the life of the patient in great and immediate jeopardy by hæmorrhage or the admission of air. The process of cicatrization in the sinus is the same as in veins, and is accomplished in the same brief period of time. In accidental wounds of the sinus, ligation should be resorted to whenever the orginal defect in the skull is sufficient to permit the necessary manipulations, or when simpler measures have failed to accomplish the same object.

Implantation of an aseptic sponge into a wounded sinus should be resorted to in all cases of wounds of the lateral walls of the sinus, in cases of accidental wounds where ligation is impossible and where other measures have failed to arrest the hæmorrhage. The sponge should be large enough to make gentle pressure upon the inner surfaces of the sinus, and yet sufficiently firm to arrest the circulation in the vessel so as to prevent the escape of blood into the subdural space. The hæmostatic action of the aseptic tampon is made more efficient by adding external compression, applied in the form of a graduated aseptic tampon. If the wound remains aseptic the sponge forms a nucleus for the thrombus and is infiltrated by connective-tissue cells from the intima and adjacent tissues, and is gradually removed by absorption as the definitive obliteration of the vessel proceeds. Small wounds of the sinus can be readily and safely closed with the lateral ligature applied in the same manner as in similar wounds of the veins.

In recapitulation we are warranted in stating the following conclusions:

1. Elevation of the head is the direct and most essential cause

in the production of air-embolism through a wound of the superior longitudinal sinus.

2. Suturing of a wound of the superior longitudinal sinus as a hæmostatic procedure is unreliable, and in most instances anatomically impossible.

3. Prophylactic ligation of the superior longitudinal sinus should be resorted to in all cases where this vessel is involved, in extirpating tumors of the dura mater.

4. Implantation of an aseptic sponge into a wounded longitudinal sinus will arrest hæmorrhage without interfering with the definitive obliteration of the vessel, and deserves a trial in cases where the lateral walls of the sinus have suffered injury and where ligation is impracticable.

VIII. Immediate Cause of Death after Intravenous Insufflation of Air.

Various theories have been advanced to explain the injurious effect of the presence of air in the circulation. Bichât[1] attributed death resulting from intravenous injection of air to cerebral anæmia produced by the presence of air in the cerebral vessels, asserting at the same time that a very small quantity would suffice to produce this effect. As the first argument in favor of this view, he claims that the heart continues to beat for some time after the cessation of animal life. Secondly, air injected through one of the carotids produces death in the same way as when introduced into the veins. Thirdly, the cases reported by Morgagni, where death was attributed to the presence of air which was found in the cerebral vessels at the post-mortem examination, and which was supposed to have developed there spontaneously. Fourthly, all examinations after death revealed the presence of frothy blood mixed with air-bubbles, in both ventricles. Fifthly, air injected into one of the divisions of the portal vein produces no ill-effects until it reaches the general circulation. Sixthly, the almost instantaneous death observed in some instances is due to the acceleration of the heart's action, and consequently the rapid conveyance of air into the cerebral vessels. Seventhly, the existence of convulsions, which he ascribes to the irritating quality of the air on the brain. He summarizes as follows:

[1] Physiological Researches on Life and Death, p. 186.

"We shall conclude that in the accidental mixture of air with the blood of the venous system, it is the brain which dies the first, and that the death of the heart is the consequence of the death of the brain."

Magendie, in commenting on Bichât's views concerning the manner of death from intravenous injection of air, remarks: "This is not correct, and death takes place, on the contrary, by the cessation of the motions of the heart. The right ventricle is filled with air, and this air, dilated by heat, so distends it that it can no longer contract." Magendie also claimed that small quantities of air in veins will not result in death, and that life is in jeopardy only when the air is injected suddenly and in considerable quantity. He relates the details of an experiment which he made on a horse, where he injected in rapid succession into the veins of the animal forty syringefuls of air, and three syringefuls into the carotid artery. The capacity of the syringe was seventeen centilitres. The animal died three minutes after the last injection. At the examination of the body he found air in the azygos vein and in the thoracic duct which contained much lymph, as well as in the lymphatic vessels of the internal surface of the lungs. The heart was enormously distended with air mixed with a small quantity of blood.

Morgagni, Brunner, Sprœgel, and Nysten referred the cause of death to the same source—over-distention and paralysis of the heart. When death was not produced by the mechanical effect of the air on the heart, then the consecutive symptoms were referred by Nysten to an obstruction of the lungs produced by the accumulation of air in the ultimate divisions of the pulmonary artery. He observed that the embarrassment in respiration often appears as late as twelve hours after the introduction of the air, and becomes greater and greater; the bronchi are filled with a viscid fluid, and the animal usually dies on the third or fourth day. In such instances no air was found in the heart or the vessels, but the lungs, instead of being pink-colored, were grayish, tinged with brown, and loaded with frothy blood and mucus. The same views were entertained by Boerhaave, Kettler, and Beck. In such cases death results from asphyxia from the mechanical obstruction to the passage of the venous blood through the pulmonary circulation.

Mery accepts the views of Mercier published in 1839, who attributed death to the fact that the blood mixed with air becomes

frothy, enters the pulmonary capillaries and obstructs them. Physicists are aware that a capillary tube which readily admits the passage of air or water offers a great resistance to a mixture of air and water: this mixture causes a series of bubbles, separated by minute septa of liquid. Poisenille has shown by a series of experiments that such in fact is the cause of death whenever air mixed with blood has obstructed the pulmonary capillaries. The right heart remains over-distended and cannot be emptied.

Blundel[1] studied the effects of the intravenous injection of air in his experiments on transfusion of blood. He injected five drachms of atmospheric air into the femoral vein of a small dog in quantities of a drachm each at a time, without any serious effects. The symptoms observed were sighing respiration, irregular pulse, muscular tremors, and vomiting, all of which, however, subsided after a brief space of time, and the animal recovered completely in three days. A second experiment was made on the same animal by blowing three drachms of pulmonary air into the femoral vein without even producing much *temporary* inconvenience. He concluded that it seemed indisputable that small quantities of air may be introduced into the circulation without destroying life. Dr. Haighton made the same experiments with intravenous injections of air, and with like results.

A series of experiments were made by Panum.[2] In the first experiment five cubic centimeters of air were injected into the lower portion of the jugular vein of a small dog. No symptoms followed immediately after the operation. Four days subsequently the weight of the animal was reduced from 3540 to 3030 grammes. The tissues around the point of puncture were inflamed. On the fifth day the animal was killed. The skin of the animal was dotted with spots of ecchymosis resembling the extravasations as they occur in the disease known as morbus maculosus Werlhofii. In the vicinity of the wound, the tissues were emphysematous, emitting an offensive odor. Among other post-mortem appearances the lungs presented several gray superficial stripes and spots, one to two lines in diameter. In the middle of several of these patches were found empty spaces which Panum regarded as encysted air-bubbles. In addition, small

[1] Medico-Chir. Trans., vol. ix. p. 65.

[2] Experimentelle Beiträge zur Lehre von der Embolie. Virchow's Archiv, vol. v. p. 499.

isolated nodules were also found which contained in their interior small bubbles of air. These nodules contained also numerous nuclei and fat globules.

In the second experiment ten cubic centimeters of air were injected into the lower portion of the jugular vein of a small one-year-old dog. During the first three days nothing was observed with the exception of rapid emaciation. On the fourth day the animal began to lose hair not only in the vicinity of the wound, as in the first case, but over the entire surface of the body. Later inflammation and ulceration attacked the point of operation. On the eleventh day the animal was killed. The lungs again presented subpleural nodules, from the size of a pin's head to that of a grain of sand, in which could be found large cells filled with fat molecules, granular cells, and fat globules in large number. Air could not be found in any of them, and their relation to the capillaries of the pulmonary artery could not be determined.

In the third experiment thirty cubic centimeters of air were injected into the jugular vein without producing any alarming symptoms, except rapid and deep respiration. The next day no change was observed, but on the following day the animal was found dead. A careful examination revealed punctiform extravasations in different portions of the brain, stomach, and liver. The wound showed a healthy appearance. The lungs contained many very small yellowish-white nodules and points of extravasation one to two lines in diameter. The hæmorrhage infarcts contained each a minute cavity filled with air. The nodules also contained air. From these experiments it appears that the air-emboli which passed through the pulmonary capillaries produced local disturbances in the minute vessels in the skin and gastro-intestinal canal, while the air-emboli in the ultimate branches of the pulmonary artery gave rise to circumscribed foci of inflammation.

Picard[1] found after insufflation of air into the portal vein, intense hyperæmia in the distal portion and radicles of the vessel, the same as after ligation. At the commencement of the insufflation the blood pressure in the femoral artery and one of the rectal veins was about the same; after a while the pressure in both was simul-

[1] Sur les injections d'air dans la veine porte. Gazette Médicale de Paris. No. 6, 1873.

taneously diminished, but the positive pressure lasted longer in the vein than in the artery. The action of the heart was increased, the respirations became slower, and the temperature in the rectum was gradually reduced. As an interesting physiological fact it is mentioned that after insufflation of air into the portal vein no sugar could be found in the liver, and the fibrin in the portal blood was diminished.

The experiments of Magendie, Bouillaud, and later those of Couty,[1] prove conclusively that in cases of entrance of air into a peripheral vein the air collects almost exclusively in the right side of the heart, only a minute quantity entering the left side through the pulmonary capillaries. Referring to this question Flint says: "The production of death from air in the veins is purely mechanical. The air, finding its way to the right ventricle, is mixed with the blood in the form of minute bubbles and passed into the plumonary artery. Once in this vessel, it is impossible for it to pass through the capillaries of the lungs, and death by suffocation is the inevitable result if the quantity of air be large. It is because no blood can pass through the lungs that the left cavities of the heart are usually found empty."[2]

If the quantity of air introduced is small, or the entrance repeated in small quantities, the air collects in the capillaries of the pulmonary artery as air-emboli, obstructing the circulation in the impacted vessels; but a sufficient number of vessels remain pervious to maintain the circulation, and life is prolonged until the equilibrium of the circulation is restored by the absorption of the adventitious air. No traces of air are found in the arteries, only a small quantity passing into the venæ cavæ through the tricuspid valve, which has been rendered insufficient by the presence of air. When a considerable amount of air has entered the right ventricle of the heart mixed with the blood, the air is separated from it, and, its specific gravity being less, it rises to the highest point of the chamber in contact with the anterior walls. It also expands, and by this overdistention it impairs the muscular contractility which even in a normal condition is insufficient to completely empty the cavity.

The impediment to the circulation being the presence of the

[1] Etude experimentale sur l'entrée de l'air dans les veines, Paris, 1875.
[2] Physiology of Man, Blood, Circulation, Respiration, p. 323, 1866.

large air-embolus in the right ventricle, which on account of the higher temperature increases in volume, sudden death will take place in the diastole by an arrest of the heart's action from paralysis by over-distention. If the animal escapes instantaneous death from this cause, the heart is inadequate to force the blood from the right ventricle through the pulmonary circulation, as its efforts are expended in compressing the air; only a minute quantity of blood being forced into the lungs. In proportion as the amount of air and blood in the right ventricle increases, the right side of the heart is expanded and the volume of blood in the lungs and the left heart is diminished. At last the distended walls of the heart prevent perfect closure of the tricuspid valve, giving rise to venous pulsation, a constant symptom in all cases of air-embolism which prove rapidly fatal. On the advent of this complication the intra-arterial pressure in the pulmonary and peripheral arteries diminishes, which further enfeebles the pulmonary circulation; at the same time it produces acute anæmia of the brain, and death results from anæmia of the brain or asphyxia.

Such is the mechanism of death in cases of entrance of air into the venous circulation; it also offers an explanation why in these cases the air is found mostly in the right side of the heart and the large venous trunks. These facts also corroborate the observations of experimenters that certain animals succumb more readily to the presence of air in veins than others. The tolerance of intravenous air is most marked in animals with well-developed respiratory organs and a proportionately powerful right ventricle. In horses, for example, the volume of the right cavities is smaller and the muscular structure more powerful, circumstances which explain the fact that entrance of air into the veins of these animals does not easily kill them. The circulatory apparatus of the dog offers the least resistance to intravenous air. Rey blew air into the jugular veins of horses after venesection without producing death. Small amounts of air produced no result whatever, and a volume of air equivalent to two expirations proved fatal only in debilitated animals. Some animals remained well after leaving a cannula in the jugular vein for several hours. Death was sure to follow if after the insufflation of air the vein was ligated. Animals who had previously lost large quantities of blood readily succumbed to intravenous admission of air.

Laborde and Muron, who studied the effects of intravenous and intra-arterial insufflation of air, placed great stress on the manner in which the injections were made, in determining the gravity of the symptoms. They observed that in case the insufflations into veins were made slowly and repeated at intervals, large quantities were tolerated without exciting serious symptoms. If, on the other hand, they were made suddenly and with force, and the quantity of air was considerable, death resulted almost instantaneously from arrest of the heart's action in the diastole, an occurrence which was attributed by these authors to over-distention of the right side of the heart.

In repetition, it may be stated, that the immediate cause of death after intravenous injection of air has been referred by different experimenters to:

1. Mechanical over-distention of the right ventricle of the heart and paralysis of this organ during the diastole.

2. Acute cerebral ischæmia.

3. Asphyxia from obstruction to the pulmonary circulation consequent upon embolism of the pulmonary artery.

IX. Intra-Arterial Insufflation of Air.

As the accidental admission of air never takes place in wounds of the arteries on account of the high degree of intravascular pressure and the absence of any aspiratory force, it is not surprising that the effect of the artificial introduction of air into these vessels has been made less frequently an object of experimental research than intravenous insufflation of air. The subject is devoid of any practical value, and the interest attached to it is of a purely scientific nature. As we have already seen, Bichât entertained the idea that atmospheric air acts as a direct irritant to the substance of the brain when brought in contact with that organ through the medium of the cerebral vessels, and death from insufflation of air, whether into veins or arteries, was invariably attributed by him to cerebral anæmia.

Panum,[1] in his researches on embolism, made arterial insufflation of air also a subject of experimentation. A rapidly fatal termina-

[1] Op. cit.

tion followed the injection of 4 cubic centimeters of air into the lower portion of the carotid artery of a medium-sized dog. The infundation was followed immediately by severe general convulsions, alternating with violent attacks of rage. The animal foamed at the mouth, and had involuntary discharges from the bladder and bowels, the eyes became prominent, and the pupils, at first dilated, contracted, and remained so permanently. The animal soon became quiet and motionless. Respiration and heart's action slow. The right anterior and both posterior extremities were extended and rigid, while the left front leg remained relaxed. Conjunctiva insensible, while touching the cornea produced contractions of the eyelids. For two hours the animal remained in a condition resembling anæsthesia, without changing its position, with slow pulse and respiration, when life ceased without a tremor or convulsion.

The post-mortem examination showed numerous punctiform ecchymoses in the gastro-intestinal mucous membrane, the liver, diaphragm, and abdominal muscles. The superficial vessels of the brain, more particularly the veins, were extremely hyperæmic: the jugular veins were distended to their utmost with blood. The small arteries contained many air-bubbles, so that the smallest vessels presented varicose dilatations which resembled a string of pearls. The large vessels at the base of the brain also contained air, and numerous red spots were disseminated throughout the white substance of the brain.

Laborde and Muron[1] witnessed after the introduction of 20–60 cubic centimeters of air into the carotid artery of dogs, when injected in a peripheral direction, that death was produced rapidly and was always preceded by tetanic convulsions and labored respiration: while if the quantity of air injected was smaller, and especially if the air was thrown in in divided doses, the animal often survived the experiment for twenty-four hours. In the latter class of cases the operation was followed by tetanus, vomiting, paralysis, and coma. The autopsy revealed softening of the brain, and capillary hæmorrhages, especially in the middle portion of the brain, the medulla oblongata, and in the posterior lobes of the cerebrum. The intra-arterial insufflations of air in all these experiments were immediately followed by grave cerebral symptoms which can only be interpreted

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[1] Virchow u. Hirsch's Jahresbericht, vol. i. 1873, p. 268.

by the constant post-mortem appearances, air-embolism of the cerebral vessels, and extreme ischæmia of the brain.

The presence of air in the arteries, on the left side of the heart, is followed by an entirely different series of phenomena than in the veins on the right side of the heart. The acute ischæmia of the brain thus induced is invariably manifested by tetanic rigidity of the voluntary muscles and almost complete suspension of the respiratory movements of the chest. The contractions of the left ventricle are so powerful as to overcome these additional impediments and to completely evacuate the chamber. The air is expelled as soon as it enters and is distributed throughout the whole arterial system. It may be readily conceived that the air when it has reached the aorta will rise into the carotid arteries and thence into the cerebral vessels, distending them to their utmost capacity. In such instances death results from sudden cerebral anæmia before the air can gain entrance into the venous system through the capillaries.

That the presence of air is detrimental to the nervous system has been established by experiments on animals. Bohnius attributed to the air when introduced into the vascular system poisonous properties, and this opinion is entertained by Neudörfer even at the present time. Copeland believed that the oxygen of the adventitious air combines with the carbonic oxide in the venous blood, producing carbonic acid. These and similar theories do not explain the phenomena observed after insufflation of air. The symptoms during life, and post-mortem appearances point directly towards physical obstruction in the blood-vessels by air-emboli, which suspends the function of one of the vital organs, and consequently must be regarded as the immediate or direct cause of death.

Insufflation of air into the carotid artery towards the brain is almost immmediately fatal. If a moderate quantity of air is forced through the arterial system into any other organ except the brain, it does no particular harm, except by forming a temporary obstruction in the circulation, and is in a short time removed by absorption. This fact may have induced Flint to make the following remarks concerning this subject:[1] "Air injected into the arteries produces no such serious effects as air in the veins. It is arrested in the capillaries of certain parts, and in the course of time is absorbed without having produced any injury."

[1] Op. cit., p. 324.

The danger arising from the introduction of air into the arteries or left side of the heart comes from obstruction to the circulation through the cerebral vessels by air-emboli, and the cessation of the functions of the brain consequent upon an almost complete ischæmia of this organ. The mechanical distention of the left side of the heart by the accumulated air is overbalanced by the powerful contractions of the left ventricle, which are sufficient to empty the chamber almost completely, and to force the air into the ultimate distributions of the arteries, causing acute anæmia in distant organs, but more particularly in the brain. In these instances the air is forced directly into the cerebral vessels either by the injecting force, or the powerful contractions of the left ventricle; and if death takes place, it follows as the direct result of acute cerebral ischæmia.

X. Clinical Study of Air-Embolism.

All physiologists agree that regular and deep inspirations produce a powerful aspiration in the large veins near the base of the heart, more particularly in the jugular and subclavian veins. This fact is so well known that the base of the neck and the clavicular regions are frequently referred to as the "danger zone." During the inspiratory act the chest expands, and the flow of venous blood is accelerated towards the cardiac or proximal side. A diversity of opinion still exists among authors in regard to the distance to which this force directly affects the venous circulation. Experiment and clinical observation have shown that the danger of entrance of air into wounded veins is increased as the wound approaches the heart.

Berard studied the anatomical conditions of the vessels where entrance of air has most frequently taken place, and he came to the conclusion that this accident can happen only when the wounded vessel is empty, and its walls are prevented from collapsing, and the wound remains patulous. He found these conditions normally present in the sinuses of the dura mater, the hepatic veins, the superior vena cava, the internal jugular, the subclavian, and axillary veins, because the walls of all these vessels are firmly fixed to the adjacent tissues, which prevents their collapse on being wounded.

It has been further shown that the admission of air is favored by pathological conditions which affect the veins in a similar manner, as the existence of induration of their walls, the result of chronic

inflammation, or infiltration by neoplasms. Experience has corroborated these views, inasmuch as it has been shown that this accident has occurred most frequently in operations in the vicinity of veins which, from their anatomical location, are prevented from collapsing by firm and unyielding layers of fascia, and vessels which are, or have become, adherent to unyielding tissues. Again, it is always, with reason, feared in removing tumors which have become adherent to large veins, as the morbid process has frequently so impaired the normal resiliency of the vessel as to keep its lumen patent in the event of its being wounded during the dissection.

In thirty-three cases of intravenous aspiration of air collected by Couty,[1] air entered the external jugular nine times, the axillary eight times, the internal jugular five times, the subscapularis three times, the facial twice, the anterior jugular twice, the occipital twice, and twice one of the anterior thoracic veins in close proximity to the clavicle. In 1864 Greene collected sixty-seven cases where air had entered a vein during an operation. The greater number of these cases occurred during extirpation of tumors in the region of the neck, chest, and axilla. Twice the accident took place in disarticulating the humerus at the shoulder joint (Cooper, Delpech); once on extirpating the scapula and clavicle (Mussey); twice on tying the subclavian artery (Rigaud, Clemot); three times on bleeding from the external jugular vein; three times on bleeding from the median vein; and once on passing a seton-needle through the tissues in the regions of the neck. Among the wounded veins the external jugular is mentioned thirteen times, the internal jugular ten times, the subclavian and axillary each once. In the remaining cases the vein is not specified, or the injury involved a branch in close proximity to the specified vessels.[2]

All causes which interfere with the free return of venous blood prevent the admission of air; while, on the other hand, all influences which promote the venous circulation, such as an unimpaired *vis a tergo*, regular deep inspiration, and the force of gravitation predispose to this accident. Soon after Beauchêne made known his case, the Royal Academy of Medicine of Paris appointed a commission to investigate the subject. In the report it is stated that the results of the experiments, which were made principally on dogs, had proven

[1] Op. cit.

[2] American Journal of the Medical Sciences, 1864, p. 38.

that the conditions necessary to determine the entrance of air consisted in making the wound in the vein anywhere within the area of the venous pulse, or, at any rate, only a short distance from it. If the wound was located at a greater distance and beyond the influence of the venous pulsations, no air would enter, although the wound was kept open.

The experiments were also to determine the extent of the venous pulse, and the conclusions arrived at were that the brachial and axillary veins were beyond the venous wave, while the subclavian and lower third of the jugular veins were the seat of pulsations; consequently wounds of the veins in these localities were liable to admit air. The sound produced by the entrance of air is described as resembling the lapping of a dog or cat, and it always occurred during, and synchronous with, inspiration; but sometimes, when it was heard more frequently, it accompanied the diastole of the right ventricle. After the air had entered the vein, the sound which could be heard on auscultation over the heart was described as a "bruit de soufflet," synchronous with the action of the heart. In regard to the effect of the aspirated air it was decided that, in order to produce a fatal result, it was not only necessary that the amount of air introduced should be considerable, but that it should be thrown into the vein with some degree of force.

Hertwig called special attention to the fact that aspiration of air is not as frequent an accident as is generally supposed, and that for its occurrence the peripheral flow of blood to the wound must be obstructed, that the edges of the vein wound must be drawn apart, and finally, that the introduction of a cannula into the vein is necessary to admit a sufficient amount of air to produce serious results.

The first case of admission of air into a vein that was recognized and verified by a post-mortem examination, occurred in the practice of Beauchêne, and is described by F. Magendie.[1] As the case is of great historical and scientific interest, I will relate it as described by Magendie.

A locksmith, twenty-three years of age, had for five years a large tumor on the right shoulder and clavicle. His acute sufferings induced him to enter the hospital to have it removed. It was necessary in the operation to remove the middle portion of the clavicle. Thus far the success was complete; but

[1] Physiological Researches on Life and Death, by X. Bichât, with notes by F. Magendie. Translated. Boston, 1827, p. 188.

little blood was lost, the pulse was good, and the breathing easy, when the patient suddenly cried out: "My blood is leaving my body! I am dead!" At the same moment he became stiff, lost his consciousness, and was covered with a cold sweat. A singular and rather loud noise was heard in the interior of his chest. The surgeon thought that he had opened the pleura by removing a portion of the clavicula, and thus given access to the air and to the blood to the right side of the thorax. The fingers of an assistant were immediately thrust into the bottom of the wound with a view of stopping the supposed opening in the pleura, and the surgeon endeavored to introduce into the thorax the extremity of a sound of gum-elastic. When he thought that he had succeeded he drew with his mouth the air which he supposed to be effused in the pleura. He wished then to proceed to the dressing, and, in order to do this, he substituted for the fingers of the pupil, which were at the bottom of the wound, a sponge covered with wax; but the moment the sponge took the place of the fingers, the same noise that was at first heard, and which had ceased in an instant, was renewed with more force than before. The syncope and cold sweat still continued. Water thrown into the face made him give some signs of life, but he died a quarter of an hour after the appearance of the accident I have first described, and forty-five minutes after the commencement of the operation. The body was examined the next morning. They expected to find the right pleura open, much blood and air effused into its cavity, and the lungs on that side collapsed. Nothing of the kind was found. The pleura was whole and there was no effusion in it. The lungs were as usual, but an opening of half an inch in extent was discovered in the external jugular vein, at the place where this vein opens into the subclavian. The cavities of the heart were large, but contained no blood. Bubbles of air were observed in the vessels of the brain; the other vessels were not examined.

In order to study some of the conditions under which air has been aspirated into veins, and for the purpose of ascertaining the effects of such accidents in man, I will introduce a number of well-authenticated cases which will represent a great diversity in the point of entrance, and will also aid in the establishment of the fact that this accident can occur outside of the regions of venous pulse, always occurs during inspiration, and is never produced by the aspiratory function of the heart.

External Jugular. Barlow's case.[1] The patient was a female suffering from a tumor seated on the side of the neck, which had been increasing in size for several years; its base was extensive, and occupied the whole of the lateral and posterior parts, extending from the ear to near the sternum, and sidewise from the thyroid gland to the sterno-mastoid muscle, under which a part of the tumor was situated. The patient was seated in a reclined chair, supported by assistants. Two superficial elliptical incisions, ten inches in length, were

[1] Medico-Chirurg. Trans., vol. xvi. p. 29.

made downwards from a little below the ear, "when on proceeding to dissect the skin aside to get at the basis of the tumor, a sudden and unexpected hissing and gurgling noise rushed obviously from a large divided empty vein, and the patient expired instantly, without either sigh, groan, or struggle, and every effort to restore animation became fruitless." The divided vein appeared larger than the normal external jugular, but the reporter believes that it was this vessel or an anomalous vessel greatly enlarged. As the incisions must have traversed the external jugular, according to his own description, it was undoubtedly this vessel which was injured. It is distinctly stated that the vessel was flabby and empty, and that the instant the atmospheric air gained access and filled the vacuum, the hissing noise ceased, the patient expired, and the mouth of the vessel collapsed.

Remarks.—In this case the admission of air was favored by the dilatation of the vein, and the semi-erect position of the patient. The latter factor produced the emptiness of the vein. The instantaneous death without any symptoms preceding it can only be explained by the fact that the air entered the right ventricle with force and in large quantity, and arrested the heart's action by overdistention.

Internal Jugular. Ulrice's case.[1] The operation was performed for the removal of a tumor involving the left side of the neck. It was found that the tumor was attached to the deep vessels of the neck, and in severing its connection, the internal jugular vein was opened. No hæmorrhage followed, the vessel remained open like an artery, and air entered immediately. The patient fainted; twitching of the muscles of the face, opisthotonos, a few slow respirations followed, and the patient was dead. The vein was found obliterated above the incision, and thickened, and more resistant than normal where the wound was inflicted. The reporter attributed the ingress of air to aspiration of the heart, and death to paralysis of this organ.

Remarks.—The pathological changes in the vein above the wound, interrupting entirely the column of blood from above, as well as the thickening of the incised vein walls, were potent factors which determined the entrance of air. As this operation was performed before anæsthetics were used, we may be almost certain that the patient was in a sitting or half-reclining position during the operation, thus favoring greatly venous return and ingress of air. The entrance of air in this instance is brought by the author in connection with the suction power of the heart, in accordance with the prevalent doctrine of the French Commission.

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[1] Rust's Chirurgie, Berlin, 1836, vol. xvii. p. 565.

Internal Jugular. Dupuytren's case.[1] The operation consisted in the removal of a tumor of a fibro-cellular character of considerable size from the neck of a female, twenty-two years of age. No serious obstacles presented themselves until the last deep attachment was severed with the knife, when suddenly a prolonged hissing noise (*Soufflement prolongé*) was heard, resembling the sound produced by the entrance of air into a vessel from which it had been exhausted. The patient immediately proclaimed "I am dying," and instantaneously dropped down on the floor, a lifeless corpse. As no other cause was found which could in any way account for the sudden death, the fatal issue was attributed to the entrance of air into the internal jugular vein. The following account of the post-mortem appearances fully warrants this supposition: "The right auricle was distended with air like a bladder, which rushed out when cut open without any admixture of blood. Fluid blood was found in different vessels. Great quantities of air were found in all the vessels. There was no other unnatural appearance in any other part of the body."

REMARKS.—The editor of the *Medical and Chirurgical Review* explained the entrance of air in this case as follows: "It proves that the heart acts as a sucking as well as forcing pump, otherwise air could never have passed from a cut vein in the neck down into the right chambers of the heart. It is highly probable that, in consequence of the morbid state of the parts, the mouth of the cut vein had remained patulous, and thus readily admitted the air." As no mention is made of the occurrence of hæmorrhage, the vein was probably empty, a condition which might have been owing to the position of the patient during the operation or the pressure of the tumor. It is also reasonable to assume that, on account of the intimate connection of the tumor with the vessel, the former so altering the structure of the latter as to prevent closure of the wound, all of these causes combined, resulting in aspiration of air during inspiration.

Facial Vein. Mott's case.[2] The operation consisted in extirpation of the parotid gland, the seat of a scirrhous tumor. The facial vein was opened, where it passes over the base of the lower jaw, in dissecting the integuments from the tumor in the early stage of the operation, before a single artery was tied. At the instant this vessel was opened, the attention of all present was arrested by the gurgling noise of air passing into some small opening. The breathing of the patient at once became difficult and laborious, the heart's action violent and irregular, his features were distorted, and convulsions of the whole body soon followed to so great an extent as to make it impossible to keep him on the table. He lay upon the floor in this condition for nearly

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[1] Medico-Chir. Trans., vol. xvi. p. 301.

[2] Ibidem, p. 32.

half an hour, as all supposed *in articulo mortis*. The convulsions ceased gradually, his mouth was distorted, and complete hemiplegia was found to have taken place; after an hour had passed he could speak, but the use of his arm and leg was only completely recovered after the lapse of a day.

Remarks.—Although not stated, it was undoubtedly true that in this instance the facial vein was enlarged, and its walls had lost their normal resiliency, thus favoring the ingress of air. This case is also of interest, as from the predominance of the cerebral symptoms it is apparent that some of the air must have passed through the pulmonary circulation and have gained access into the cerebral vessels from the left ventricle, giving rise to symptoms of cerebral embolism, which disappeared as the air was absorbed.

Axillary Vein. Bransby Cooper's case.[1] The patient was a female, nineteen years of age, who was the subject of a malignant tumor of the right humerus which required amputation at the shoulder-joint. The operation was done by making a double flap, the subclavian artery in the meantime being compressed against the first rib. There was no loss of blood. The subclavian artery was secured, compression being kept up, as there were small vessels which required ligation. As the operator was removing an enlarged gland from the axilla, he heard distinctly a peculiar gurgling noise, like air escaping with fluid from a narrow-necked bottle. At the same moment the patient fell into a state of collapse which threatened immediate death. The face was deadly pale; the pupils fixed and insensible to light; the pulse small and fluttering, at intervals regular; respiration hurried and feeble, and at irregular intervals attended with a sigh. The patient was placed in the recumbent position, the flaps closed, and stimulants applied; but an hour elapsed before she had sufficiently recovered to be removed from the operating room. Subsequently, when placed in bed, she maintained a constant motion of alternate flexion and extension of the right leg, which continued for several days; at the same time she complained of pain, extending up the right side of the neck and head. The next day the pulse varied from 140–150 per minute, which remained the same for two days. She gradually rallied and recovered completely.

Remarks.—In this case the axillary vein was divided at a point where its walls are firmly fixed and its lumen kept patent by dense connective tissue which surrounds the vessel, a condition which predisposes to aspiration of air. Pulmonary air-emboli obstructed the passage of blood through the lungs, a circumstance which would serve to explain the rapid respiration and the accelerated action of the heart until the obstructing cause was removed.

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[1] Med.-Chir. Trans., vol. xxvii. p. 41.

Axillary Vein. Courvoisier's case.[1] The operation was performed for the removal of a recurring cancer of the breast, and included the extirpation of infiltrated and ulcerated axillary glands. As the dissection reached the upper margin of the mass of axillary glands a lapping (schluerfendes) sound was suddenly heard; at the same time the patient, a robust woman fifty-eight years of age, sank into a condition of collapse. The central portion of the vein was at once closed by digital compression, and artificial respiration, with the administration of stimulants, was successful in restoring her after the lapse of half an hour. Both ends of the vein were ligated, and the central ligature included the forceps, which were allowed to remain. The patient recovered.

Remarks.—In this instance the entrance of air was again determined by the anatomical location of the vein wound, to which may have been added cancerous infiltration of the para-vascular tissues, which rendered the vein walls still more unyielding. The amount of air admitted must have been small, to judge from the evanescent nature of the symptoms which followed.

Anterior Thoracic Vein. Amussat's case.[2] The patient was a woman, forty-seven years of age, suffering from a scirrhous affection of the right mammary gland and the subjacent and surrounding tissues. The breast and adjacent tissues had been removed, and the operator was dissecting towards the opposite side, when suddenly, on making an incision into some suspicious granulations on the inner side of, and below the left clavicle, he and three other surgeons who were assisting him heard a sudden, distinct, interrupted sound, as of air passing into a cavity through a narrow opening. The patient exclaimed, "I am dying," and appeared to be suffocating. A repetition of the same sound convinced the operator that air had entered through a wounded vein, and he placed his finger on the spot from which the sound proceeded. The patient's condition became critical, a cold sweat covered her face, her eyes were turned upwards, and all around her thought her dying. The orifice of the wounded vein could be distinctly seen. The chest was compressed with a view to force out the air from the vein, the wounded spot being compressed during the expansion of the chest. The patient soon began to show signs of improvement, when the operation was completed, and the vein with a portion of the tissue, was tied. The patient recovered completely.

Remarks.—Although the particular vein wounded in this instance is not specified, it was undoubtedly a branch of the subclavian vein, the wound being in close proximity to the latter vessel. This case furnishes a good illustration of the fact, that veins of comparatively small calibre, when wounded near their proximal

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[1] Correspondenzblatt für Schweizer Aerzte, 1880, p. 205.

[2] Gazette des Hôpitaux, July 6, 1837.

termination into a larger vessel, may serve as points of entrance of air under the same circumstances as when the principal trunk is injured.

Superficial Cervical Vein. Trélat's case.[1] M. Trélat related, at a meeting of the Société de Chirurgie of Paris, an important case in which sudden death occurred in a patient from whom he was proceeding to remove a submaxillary tumor. The patient turned ghastly pale, and the heart's action ceased suddenly. Artificial respiration and electrization of the phrenic nerve induced some respirations and a slight return of color after fifteen minutes, but ineffectually. At the post-mortem examination a small vein opening into the external jugular was found to have been partially divided; in the jugular was a long clot interspersed with air-bubbles, and other bubbles of air were found in one of the mediastinal veins and the posterior cardiac vein, and a very notable quantity of air in the right chambers of the heart.

Remarks.—Several members of the society argued that death in this instance was due to the anæsthetic, and not to the entrance of air into the vein. Roux and Giraldès claimed that in several cases of death from chloroform they had found gases in the heart, in the vena cava, and even in the veins of the pelvis, but M. Depaul, in reply, properly and forcibly pointed out that the air in this case occupied only the veins going to the heart, and the wounded vein.

Femoral Vein. The only well-authenticated case of aspiration of air into the femoral vein that I have been able to find is recorded in the *Medical and Surgical History of the British Army in Turkey and the Crimea*, vol. ii. p. 277, and refers to the sudden death of a soldier who had suffered amputation of the thigh, from this cause. Three and one-half days after the operation he died suddenly without any obvious cause. At the necropsy, twelve hours after death, it was ascertained that the right cavities of the heart were distended with a mixture of blood and air, and the same condition was found in the two iliac veins and the inferior vena cava.

Remarks.—As the time which had intervened between the operation and the fatal accident was more than three days, it is necessary to assume that the venous thrombus had been removed by suppuration, thus opening the vein for the admission of air, or that the supposed air found in the heart and vessels was not air but gas which had developed in the wounded parts, and had gained entrance into the venous circulation. This latter supposition is strengthened by the statement that the surfaces of the flaps were separated by gaseous products, and that the femoral vain was not closed but lay open on the surface of the stump.

[1] British Medical Journal, March 16, 1872.

Internal Saphenous Vein. Warren's case.[1] The operation was done for the removal of a tumor from the inner surface of the thigh. In the dissection the internal saphenous vein was wounded; the event was promptly announced by an audible and distinct sucking sound produced by the entering air. No alarming symptoms followed, as the further ingress of air was promptly prevented by closure of the vein.

Uterine Veins. That the entrance of air into the uterine veins might be a cause of danger after parturition was suggested by Legallois in 1829. Dr. John Rose Cormack read a paper on this subject before the Westminster Medical Society in 1850, in which he gave the details of three cases that had occurred in his neighborhood. Many authorities doubt the possibility of admission of air into the uterine veins after labor. Julius M. Kolb[2] alludes to this subject as follows: "I have not seen a case which convinced me that air had passed into the open veins of a recently delivered uterus, and I cannot conceive the mechanical possibility of such an occurence." Bessems, Lionet, Lever, Wintrich, Berry, and Simpson assert that they have met with such instances, and a sufficient number of well-authenticated cases have been placed on record to leave no further doubt as to the possibility of sudden death in puerperal women from entrance of air into the uterine sinuses.

In a recent number of the *Wiener Medicinische Zeitschrift*, Braun gives three fatal cases from the introduction of air into the uterine veins; in two of the three the uterine douche was used, in one to produce abortion, in the other after delivery of twins, and the patients died in a short time, one indeed within twenty minutes. Post-mortem examination showed air in the uterine veins, in the ascending vena cava, and in the veins of the heart. The third case was that of a woman who had been delivered lying upon her left side, and was then turned upon her back; massage was made over the uterus, she gasped, and died in a few minutes. Braun suggests that in the change of position a volume of air entered the uterus, and the manipulation, instead of driving it out, forced it into the uterine veins. Bischoff refers to two cases that came under his observation.[3] Dr. Draper[4] has reported two cases where instant

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[1] Gazette Médicale, No. 52.

[2] Pathological Anatomy of the Female Sexual Organs, 1868, Am. Trans.

[3] Correspondenzblatt für Schweizer Aerzte, 1880, p. 206.

[4] Boston Medical and Surgical Journal, January, 1883.

death occurred from efforts to cause criminal abortion. The post-mortem examination proved in each case the presence of air in the veins.

Mr. George May[1] reports three cases which occurred in his vicinity. The patients died respectively, immediately, six hours, and eight days after delivery, and in all of them post-mortem examinations showed the presence of air in large quantities in the inferior vena cava and the right side of the heart. An interesting account of this accident is given by Dr. George Cordwent, and relates to a case that came under his observation.[2]

His patient was twenty-eight years of age. During the delivery, at full term, her expulsive pains became urgent, and at her request she was permitted. in the absence of her medical attendant, to remain standing; after a few severe pains the child was expelled, and after falling on the floor, dragged with it the whole placenta. Almost immediately afterward a kind of gurgling sound was heard by the attendants, but whether it arose from rumbling in the bowels they could not say. The patient remained about one minute standing as before and holding on to the bed-post; she then cried out: "I can't see! I feel faint! lay me on the bed," and expired almost instantly. At the necropsy, twenty-four hours after death, it was shown that the uterus externally presented the normal appearances of a recently delivered organ, except that a portion of the wall of its fundus to about the extent of a five-shilling piece was slightly more puffy than the other portions, and, on cutting into it, air-bubbles escaped. There had been no laceration of the placental surface; the uterine cavity contained only one small clot; its lining membrane was healthy. The coronary vein of the stomach was distended; the right side of the heart was slightly gorged, and when the auricle was punctured, air-bubbles escaped with the blood which it contained.

Davidson[3] reports the case of a Hindoo woman who was admitted into the Kaira Gaol Hospital and safely delivered of a female child. The labor was in every respect normal. The placenta came away at the usual time, and there was no post-partum hæmorrhage. About three-quarters of an hour afterward the woman died without any apparent cause. There had been no hæmorrhage or convulsions. The patient had been taking some nourishment when she suddenly fell back and expired. At the post-mortem examination two hours after death the uterus was found empty, with large and somewhat distended veins; the right side of the heart contained

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[1] British Medical Journal, June 6, 1857.

[2] St. George's Hospital Reports, vol. vi.

[3] The Lancet, vol. i. 1883, p. 999.

a quantity of air mixed and churned up with blood, which escaped in bubbles; the lungs were congested; all the other organs were normal.

A most interesting and convincing case is related by Olshausen. It is most convincing on account of the painstaking and accurate post-mortem examination which was made to determine the cause of death.[1]

A robust secundipara, aged twenty-nine, was delivered at full term. The uterus was unusually distended; no albumen in urine. The labor was lingering and the uterine douche was used. The water was of 30° R. and was forced into the vagina gently by a pump. A third injection was made by a midwife. After eight minutes' use the patient began to complain of oppression. The tube was withdrawn. The patient rose in bed, immediately fell back senseless, and died in less than a minute under convulsive respiratory movements and distortion of the face. Eight minutes later bleeding by the median vein was tried, but only a few drops flowed. On touching the body distinct and widespread crepitation was felt.

Autopsy eight hours after death.—A large quantity of dark fluid blood escaped from the sinuses of the dura mater. The cerebral membranes very hyperæmic; brain normal, lungs somewhat congested, heart lying transversely, apex in fourth intercostal space. Left ventricle in firm contraction, right quite soft, something like an intestine with thick walls; the coronary vessels contained a quantity of air bubbles. Left heart contained only a small quantity of blood; the right held little, but it was frothy. The distended uterus crepitated everywhere on pressure under the hand. A number of subperitoneal vessels of medium size were plainly seen to be filled with air. The right broad ligament was strongly distended with air bubbles, and this emphysema of cellular tissue extended from the broad ligament, through the retro-peritoneal space to the inner side of the right kidney, and even below the liver to the inferior vena cava.. *The inferior vena cava was enormously distended*—it was at least an inch in diameter—containing mostly air. The uterus was divided in the median line; a placenta was attached to the anterior wall; a small flap was detached from the uterus, a second placenta was attached behind and to the right; a larger portion of this had been separated, so that there was a sort of pouch between it and the anterior wall. The two ova were uninjured. The air had gained access into the veins at the placental site. It was concluded that the tube had been passed into the uterine cavity and that air had been thrown in with the water by the pump.

It would be difficult to conceive in what manner air could be drawn into the uterine veins by the aspiratory movements of the chest or heart, as is the case in the veins about the apex of the chest. Another explanation must be sought for, and this will be

[1] Monats. f. Geburtskunde, Jan. 1865. Am. Journ. Med. Sci. July, 1865.

found in the change of structure, and the relations of the uterine veins. The veins during pregnancy keep pace with the enormous physiological hyperplasia of the uterine tissues, and are gradually converted into large sinuses, more especially the vessels at the placental site; they are simply excavations or channels in the contractile muscular walls of the uterus, their size being subject to the state of the uterine walls, whether at rest, relaxation, or contraction. When the placenta is detached, some of these sinuses are laid open, and in a normal condition their calibre is obliterated by the contractions of the uterus and the formation of thrombi.

If, from any cause, air should reach the uterine cavity, it may be aspirated into the uterine sinuses by relaxation of the uterine contractions, and, having gained access into them, it is readily forced into the circulation by subsequent contractions, the uterine walls acting the part of a suction and forcing-pump. During forcible uterine contractions the veins are nearly emptied of their contents, and, as the organ relaxes, the walls of the veins are distended and a vacuum is formed, which is filled with blood or air. Should the relaxation be slow, the empty spaces are readily filled with blood or serum in the absence of air, but if the uterus relaxes quickly the suction power is proportionately greater; and, in case air has reached the uterine cavity, it is aspirated into the open veins; and, by reaching the right side of the heart through the vena cava, it gives rise to the same train of symptoms as when it is admitted into a vein during a surgical operation in the regions of the neck.

Pulmonary Vein. Dumin's case.[1] This is the only case on record where it is claimed that death was produced by the entrance of air from a pulmonary tubercular cavity through the pulmonary vein into the left side of the heart. The patient was a young man suffering from pulmonary tuberculosis in the last stage. Physical diagnosis revealed a large cavity in the apex of the right lung. After the patient had been in the hospital for three weeks the general conditions remained about the same, while the local destructive process had been progressing. One day, after eating his dinner, he arose from his bed, fell down, and expired almost instantly without uttering a word or sound.

At the post-mortem examination, twenty-four hours after death, it was found that the apex of the lung contained a cavity of considerable size, besides extensive crude infiltrations. The left lung contained numerous nodules and three small cavities. The third cavity in the substance and near

[1] Berliner Klin. Wochenschrift, January 30, 1882.

the base of the lung contained a small amount of blood intimately mixed with air-bubbles. The heart was slightly dilated. The left ventricle was filled with blood mixed with innumerable small air-bubbles. The right cavity also contained air, but in much lesser quantity. All the larger arteries contained air mixed with blood; air-bubbles were also found in the venæ cavæ and the pulmonary artery. The arteries and veins in the brain and meninges were found distended almost exclusively with air. No signs of advanced putrefaction could be found, and none of the parenchymatous organs contained gases. The reporter explained the sudden death by the entrance of air from the small cavity in the left lung, which contained spumous blood, the air having found its way into an open branch of the pulmonary vein, and from thence into the left side of the heart. The air, which was found in the right side of the heart and veins, according to his view, had passed through the systemic capillaries. As the direct cause of death, anæmia of the brain is mentioned.

REMARKS.—It seems to me that several reasons might be mentioned which would throw doubt on the correctness of the assertion that, in this case, the immediate cause of death was owing to entrance of air into the pulmonary vein. 1. The time which had elapsed from the commencement of the attack until death took place was not sufficient to produce such an extensive distribution of air, unless it could be proved that the heart's action continued after respiration had ceased. 2. The existence of an open vessel in any of the cavities was not proven at the examination after death. 3. The body appears to have been affected by a certain amount of putrefaction, which may have been sufficient in degree, to give rise to the evolution of gases, and the putrefactive changes may have been limited to, or were at least farthest advanced in, the blood, which would explain the absence of gas in any other part of the body, except within the blood-vessels. 4. Syncope is a frequent cause of sudden death in greatly debilitated patients when the heart is called upon to perform an increased amount of labor, as when the patient suddenly assumes the erect position.

Superior Longitudinal Sinus. Volkmann's case.[1] The only fatal case of admission of air into the sinuses of the dura mater is reported by Genzmer. The patient was a female, sixty-three years of age, who was affected with a perforating sarcoma of the dura mater. The tumor was noticed about two years before the operation, and was located in the region of the posterior extremity of the sagittal suture, and for a long time gave rise to no inconvenience. For the last six months it caused intense headache. On one occasion, a physician believing that it was an atheroma, attempted its removal, but as

[1] Verhandlungen d. Deutschen Gesellschaft f. Chirurgie, vol. vi. p. 32.

the first incision gave rise to copious hæmorrhage, he desisted from any further attempts, and the wound healed kindly.

When the patient was admitted under Volkmann's care into the Clinic at Halle, the tumor presented a lobulated appearance, being composed of three parts, each about the size of a plum, and was located over the posterior extremity of the sagittal suture. On touch, the tumor was soft and elastic, and imparted to the finger distinct pulsations. Gradual compression reduced its size one-half; when the pressure was discontinued it resumed its former dimensions. On auscultation, a blowing sound was heard synchronous with the radial pulse. By pressing the end of the index finger deeply between the lobes of the tumor, a bony defect in the skull was readily detected. The conclusion was reached, that the tumor had sprung from the dura mater, and had perforated the skull by the prolonged pressure, causing interstitial absorption of the cranial vault. During the patient's stay in the hospital the tumor increased very rapidly in size. As no brain symptoms were present, it was assumed that the substance of the brain was intact.

In view of the speedy fatal issue, which of necessity would take place without operative interference, Volkmann decided to remove the tumor. The operation was done April 2, 1875. Under strict antiseptic precautions the tumor was exposed by a crucial incision, and the flaps reflected with the periosteum to the margins of the opening in the skull. The aperture in the bone measured 5.5 by 4.5 cm. in diameter. With a Luer's cutting forceps the opening was enlarged to 7 by 8 cm. The tumor, when exposed, was nearly as large as a fist, and firmly adherent to the dura mater. The dura mater was carefully divided around the margins of the tumor, which had now been liberated from all its attachments except the falx cerebri. It was now drawn forward through the opening in the skull, and the falx cerebri divided with scissors from before backwards. This step of the operation was attended by alarming hæmorrhage. As the blood was being sponged away to expose momentarily the field of operation, a peculiar and characteristic lapping sound was heard, which indicated to all present that air had entered the longitudinal sinus. At the same time the assistant, who was giving the chloroform, remarked, "She is dying." The wound was immediately compressed with a large carbolized sponge. The patient was in collapse, her breathing was interrupted and stertorous.

After a short pause, it was determined to complete the operation, but as soon as the tumor was again drawn forward, and its attachment at the junction of the longitudinal with the transverse sinuses was divided, air again entered, accompanied by the same characteristic sound. The tumor was separated rapidly from its remaining attachments, and a Lister dressing was applied in such a manner as to make at the same time a requisite amount of compression for the double purpose of arresting hæmorrhage and preventing further ingress of air. At this time the patient was pulseless, pupils dilated, extremities cold and blue. Auto-transfusion, by constricting the arms and legs with elastic bandages, had the effect of momentarily stimulating the heart, but respiration became more irregular and interrupted, and after a few more brief moments the patient died.

At the post-mortem examination, which was held on the following day, the right side of the heart was opened under water and air-bubbles escaped, showing conclusively that air had made its entrance through the longitudinal sinus. The left side of the heart contained no air. Air was also found in the pulmonary artery and the subpleural vessels. The left side of the brain had suffered more from compression by the tumor than the right. The defect in the dura mater corresponded to the opening in the skull. An additional source of hæmorrhage was detected at the posterior margin of the defect in the cranium, where the opening of a vein 5 mm. in diameter, in the substance of the bone, could be seen. Under the microscope the tumor showed small spindle-shaped cells, with a very vascular intercellular substance.

REMARKS.—In this case all circumstances favored the entrance of air into the wounded sinus. The sudden and severe loss of blood from such a large reservoir as the longitudinal sinus rendered the vessel empty, thus creating the most essential element in the causation of air aspiration. The position of the patient during the operation undoubtedly was such that the force of gravitation assisted materially in the formation of the vacuum. The walls of the sinus being rigid and attached to the surrounding structures prevented collapse of the vessel, and held the wound patulous. That death was owing to the introduction of air is sufficiently proven by the symptoms during life and the evidences derived from the post-mortem examination.

Veins of Diploë. Franck[1] asserts that he has repeatedly seen aspiration of air into the veins of the diploë after trephining. He claims that the air reaches the heart through the medium of the vertebral veins, which, from their protected position, are more favorably located for this purpose. By experiments he proved that ligation of the jugular veins does not prevent the aspiration of air through the veins of the diploë, while, on the other hand, this accident cannot happen when the vertebral veins are compressed.

As the veins of the diploë in some instances are unusually large, and their walls firmly attached to the unyielding bone tissue, they constitute channels which cannot contract in case they are injured; consequently we should *a priori* expect that aspiration of air will take place under the same circumstances as in the case of the sinuses of the dura mater, and in all extensive injuries of the cranial bones the same caution should be exercised to guard against

[1] Sur la transmission de l'aspiration thoracique jusqu' aux canaux veineux des os du crâne, etc. Gazette Médicale, No 25, 1881.

this accident. In troublesome hæmorrhage from venous sinuses in bone, the bleeding is promptly and safely arrested by implantation of an aseptic sponge, which can be left *in situ*, as it will be removed by the granulation tissue during cicatrization. In such instances the sponge is peculiarly well adapted, as the lumen of the vessel is surrounded by unyielding bony walls, which will support any amount of pressure on the part of the aseptic tampon.

XI. Experiments on Venous Air-Embolism.

The injection of air was always made into the jugular vein. The neck was shaved, and the surface disinfected with a five per cent. solution of carbolic acid. Ether was always used as an anæsthetic, the animal being kept fully under its influence until everything was in readiness to throw in the air, when the inhalation was suspended, and the animal was allowed to come out from under its influence, for the purpose of studying the effects of the air on the heart and respiration, independently of the effects of the anæsthetic. The vessel was freely exposed, usually in the lower part of the neck, by a parallel incision. After isolating it to the extent of from two to four inches, the influence of the respiratory movements of the chest on the venous circulation was carefully studied. Then a hæmostatic forceps was applied to the distal portion of the vein. Below the point of compression the blood was forced out of the vessel between two fingers, and its return prevented by applying another pair of forceps to the proximal end of the exposed vein. We had thus a bloodless portion of vein between the forceps, presenting a ribbon-like band. This was partially divided in an oblique direction for the purpose of facilitating the introduction of a cannula.

The cannula being securely fastened in the vein by a ligature, when the proximal pair of forceps were removed, and, by compressing the bulb, the air was injected with force, so as to imitate as nearly as possible the conditions present during the accidental introduction of air. The cannula was connected with a rubber-bulb of known capacity, by means of a rubber-tube. After the completion of the experiment (if the animal survived) the vessel was divided completely, and both ends ligatured with catgut, and the wound closed with a continued catgut suture. The weight of the animal and amount of air injected were estimated accurately in most instances.

Experiment 1. Sheep, weighing one hundred and twenty pounds. Left jugular vein. The vessel was opened in its lower third, but no air entered. A rubber-tube was introduced for a distance of two inches with a view of facilitating the spontaneous ingress of air, but this accident failed to occur. Air was injected, at intervals of eight minutes, in quantities of 30 c. cm each, until the enormous amount of 480 c. cm. had been introduced. After the first injection nothing was observed that indicated the presence of air in the veins or the heart. After the second dose a slight splashing sound could be heard over the cardiac region, which became louder and more distinct as the amount of air in the right side of the heart increased. The first serious symptoms observed were a tumultuous action of the heart and difficulty in breathing, which became aggravated by every succeeding injection.

Towards the end of the experiment, which lasted nearly two hours, the animal was attacked, at short intervals, by general convulsive movements. After the suspension of respiration the heart's action became very slow and feeble, and at times irregular. The immediate cause of death was plainly due to asphyxia, as manifested by the great dyspnœa and the cyanotic hue of all visible mucous surfaces. On examination after death, a few air-bubbles and only a small amount of dark blood were found in the left ventricle. The right ventricle was arrested in the diastole and contained a large quantity of very dark, almost black, spumous blood. Air-bubbles were found in a number of distant arteries of small aize.

Experiment 2. Adult, large cat. In this instance the cannula was introduced and tied in the left jugular vein. The heart was exposed before the injection was made with a view of observing directly the effects produced by sudden inflation of the right cavities of the heart. Before the air was introduced, the heart contracted regularly—artificial respirations being made for the purpose of preventing death by asphyxia. As soon as the right side of the heart was distended by the air, the left auricle and both ventricles ceased to contract, while the right auricle continued to pulsate. The pulsations were feeble and irregular. The coronary veins became filled with air-bubbles, presenting the appearance of a rosary. On opening the superior vena cava, air and frothy blood escaped, the right side of the heart collapsed, and all chambers of the heart commenced to contract regularly and with considerable force. The pulsations continued for fifteen to twenty minutes, becoming more feeble and irregular and intermittent towards the last. After death air was found in both venæ cavæ and the iliac veins. The left ventricle was completely empty. In this case, owing to the small size of the heart and the large amount of air introduced, the contractions of the right ventricle were arrested in the diastole, while respiration continued. Death took place suddenly from mechanical over-distention of the heart.

Experiment 3. Dog, weight sixty-five pounds. Injected 30 c. cm. of air into the left jugular vein. Churning sounds over cardiac region loud and distinct. Heart's action became very tumultuous and intermittent. Respirations superficial and rapid. The animal was bled from the distal end of the jugular vein to the amount of four ounces, whereupon the heart's action

became regular and the respirations diminished in frequency. The vein was divided completely and both ends were tied with fine catgut ligatures, the wound being closed in the usual manner. For a number of days the dog appeared quite unwell, showed no disposition to eat, and acted very stupidly, being inclined to sleep most of the time. Subsequently he recovered completely. In this case the intravascular pressure was promptly relieved by free bleeding, which enabled the heart to force the air through the pulmonary into the general circulation. The stupid condition of the animal was undoubtedly owing to embolism of the cerebral vessels, which disappeared after the disappearance of the air-emboli by absorption.

Experiment 4. Adult, medium-sized cat. Injected 15 c. cm. of air into left jugular vein. Heart's action arrested at once. The respirations, which were irregular, ceased a few moments later. The chest was opened at once. The right side of the heart was found enormously dilated and almost motionless. Coronary veins filled with air. The right ventricle was punctured with the needle of an aspirator and its contents withdrawn, when the pulsations were re-established. The ventricle was again inflated through the needle of the aspirator. Five minutes after this injection the pulsations numbered about 250 per minute. Five minutes later the left auricle ceased to contract, the movements of the right being irregular and about 80 to the minute. After the lapse of another five minutes the pulsations of the ventricles were only 17 a minute and a little later all movements ceased. This experiment demonstrates that the arrest of the heart's action was due to mechanical over-distention, as aspiration of the right ventricle was followed by regular and strong contractions in all cavities of the heart. The contractions were not the result of the mere mechanical irritation of the heart by the puncture, as other and equally severe irritants had been previously applied without producing any effect.

Experiment 5. Dog, weight thirty-five pounds. Before operation, respirations 40, pulse 140. Injected 20 c. cm. of air into right jugular vein. Convulsions followed, which lasted for about two minutes. Respiration rapid and stertorous. Pulse 300. After five minutes the animal made repeated attempts to get up and walk, but invariably fell down on account of imperfect control over the movements, or paralysis of the posterior extremities. Half an hour later the animal was able to walk but appeared very feeble. Pulse 124, respirations somewhat accelerated. Recovery was complete. In this case the equilibrium of the circulation was soon restored, and the air in the right side of the heart passed through the pulmonary into the general circulation in a very short time, as was evident from the presence of symptoms indicative of embolism of some of the vessels in the cerebro-spinal centers.

Experiment 6. Dog, weight seventy-five pounds. Injected 60 c. cm. of air into the right jugular vein. Churning sounds loud and distinct; heart's action labored. Respirations exceedingly rapid, later stertorous. The animal recovered rapidly from the immediate effects of the air-embolism, and was soon as well as before the operation.

REMARKS.—These experiments tend to prove the following statements:

1. A small amount of air in the right side of the heart in a healthy animal gives rise only to temporary symptoms referable to the heart's action and the pulmonary circulation.

2. When air has been introduced into the right side of the heart in such quantities as not to arrest the contractions of the heart at once, it is forced through the pulmonary capillaries into the left side of the heart by the contractions of the right ventricle.

3. The danger attending the insufflation of air into veins is proportionate to the amount of air introduced, as well as to the capacity of the right ventricle to resist intra-cardiac pressure.

4. When a fatal dose of air has been introduced into the venous circulation, death takes place almost instantaneously from arrest of the heart's action, or later from suffocation.

5. Spontaneous ingress of air into a wounded, healthy jugular vein never occurred in these experiments, and must be considered almost a physical impossibility, as the resilient walls of the wounded vein collapse readily when exposed to atmospheric pressure.

Dogs weighing about thirty pounds would usually recover in a short time after an injection of thirty cubic centimeters of air, while double that amount generally constituted a fatal dose. Sheep required a proportionally larger dose to produce a fatal result. These experiments also tend to prove that animals of the same kind and species do not manifest the same degree of tolerance to the presence of air in veins. Young animals succumb more readily to its effects; in the adult animal the degree of tolerance depends on the development and contractile power of the right ventricle. In all cases where life was prolonged for a considerable length of time after the injection of air was made, and the ventricular contractions were not much impaired, bubbles of air were found in the left side of the heart, showing conclusively that the air must have passed from the right ventricle through the pulmonary capillaries.

In experiments 3 and 5 the well-marked cerebral disturbances were undoubtedly produced by secondary air-embolism of the vessels of the brain and spinal cord, since these disturbances disappeared after the removal of the emboli by absorption. When the same amount of air was administered in one dose, it always proved more dangerous than when injected in divided doses. This simply means,

that during the interval between the injections, sufficient time had elapsed for the right ventricle to force at least a portion of the air through the pulmonary capillaries into the general circulation; thus preventing for a time at least a fatal degree of intra-cardiac pressure. The greater the development of the right ventricle, the greater the tolerance of the animal to the presence of air in veins. This statement is well exemplified by the fact that in horses a larger amount of air is required to produce death, while in dogs a much smaller proportionate dose will result in death. This is because in the former animals the right ventricle, from its proportionately greater strength, is more competent to perform an additional task.

If death followed immediately after the injection, the dose was usually a large one, the heart's action having been suspended before respiration ceased, and on post-mortem examination the right ventricle and auricle were always found over-distended and tympanitic, containing a moderate amount of blood not intimately mixed with a large amount of air, while the left side of the heart was nearly or completely empty. If death occurred some time after the injection, great dyspnœa was observed, lividity of the mucous membranes, tumultuous action of the heart, and cessation of respiration prior to stoppage of the action of the heart; showing conclusively that death took place from carbonic acid intoxication. In these cases the necropsy revealed a lesser degree of distention of the right chambers of the heart, which invariably contained spumous blood or blood intimately mixed with air.

The pulmonary artery and its branches were filled with air and spumous blood, and bubbles of air and a small quantity of blood were present in the left ventricle. In opening the jugular vein I have always noticed that the vessel would promptly collapse as soon as hæmorrhage ceased, being transformed into a pale, round cord, in which the wound could be found only with great difficulty. Air was never seen to enter, even if the wound and a portion of the vein were kept patent with forceps or a rubber-tube.

I frequently arrested the column of blood in the vein by applying a compressing forceps above, and opening the vessel below, thus creating a favorable condition for the spontaneous entrance of air, but the result remained the same. It is therefore only reasonable to assume that air will enter spontaneously only in case a vein near the heart is wounded, the walls of which are prevented from collaps-

ing by fixation of its tunics to adjacent, unyielding structures, or in case the vein-walls themselves have lost their resiliency by previous pathological changes.

XII. Experiments on Arterial Air-Embolism.

Experiment 1. Medium-sized dog. The left carotid artery was exposed and isolated, and two hæmostatic forceps applied about two inches apart. The artery was divided between them, and the proximal end secured by a ligature. Into the distal end the cannula of the injecting bulb was introduced and fastened with a ligature. When the animal had fully recovered from the anæsthetic, the forceps were removed, and 80 c. cm. of air were injected at once and with considerable force; the cannula was then removed and the artery ligated. The animal collapsed almost instantaneously, and respiration was suspended for nearly two minutes. The animal appeared motionless and in a condition of profound stupor. Heart's action tumultuous and very rapid. Two minutes after the injection churning sounds were audible over the cardiac region. When respiration was re-established the movements of the chest were slow and irregular, gradually becoming slower and slower until, after about fifty attempts, they ceased entirely. The limbs were rigid, and the trunk in a position of opisthotonos. The heart continued to contract for about two minutes after respiration had ceased.

All vessels leading to and from the heart were carefully ligated, and the organ removed and examined under water. The coronary veins contained bubbles of air. All cavities of the heart contained air, the largest amount being found in the left auricle. Coagula were present in all of the chambers, except in the left auricle. The circle of Willis was distended with air, as were many of the smaller vessels of the brain and its membranes. The cerebral vessels were gorged with dark blood. The air injected into the carotid artery had evidently passed directly through the cerebral capillaries into the venous circulation, giving rise to venous and general air-embolism. In the beginning, respiration was immediately suspended from temporary suspension of innervation, but was re-established as soon as the amount of air in the cerebral vessels had lessened sufficiently to allow a better blood supply. It, however, ceased definitely under symptoms expressive of extensive embolism of the pulmonary artery.

Experiment 2. Sheep, weight ninety pounds. Left carotid artery prepared as in previous experiment, only that the air was injected in a central direction, towards the heart. After the animal had recovered almost completely from the effects of the anæsthetic, 150 c. cm. of air were thrown in, and the proximal end of the artery was tied. The animal was at once thrown into a tetanic state, with rigid limbs and retracted neck. All reflex movements and sensations were completely suspended. The heart's action was irregular and tumultuous, and over the cardiac region distinct churning sounds were heard. Respirations exceedingly rapid. The mucous membranes accessible to sight

presented a strikingly pale and anæmic appearance. Death occurred in fifteen minutes, respiration ceasing first.

Examination immediately after death showed the right ventricle greatly distended and tympanitic on percussion. It contained spumous blood, air, and a few small coagula. Left ventricle contained only a minute quantity of spumous blood and fine blood clots adherent to the endocardium. Air-emboli were found in almost all vessels throughout the body. Coronary arteries distended with air. Jugular veins contained more air than blood. Basilar artery and superior longitudinal sinus contained a large amount of air. The tongue and other distant organs extremely anæmic.

Although this large quantity of air was thrown directly into one of the large arteries, it was forced into the smallest vessels and through the capillaries into the veins and the right side of the heart by the powerful contractions of the left ventricle, giving origin to a combination of symptoms arising from arterial and venous embolism. Death was finally produced in a similar manner as if air had been injected directly into the veins. Some of the air had passed all the capillaries and was found in the left side of the heart.

Experiment 3. Medium-sized adult cat. With a view to ascertain how soon air would pass through the capillary vessels after injecting it into the carotid artery, the jugular vein on the opposite side was opened before the injection of air was made. About 15 c. cm. of air were thrown into the carotid artery in a peripheral direction. The animal was immediately seized with convulsions and died in less than a minute. Respiration ceased first. Air was seen to escape from the wound in the jugular vein, and was also found in nearly all of the vessels throughout the body.

On opening the chest the right side of the heart was found distended to its utmost, and tympanitic on percussion. The contractions of the right auricle were twice as rapid as the ventricular contractions. The movements of the left auricle were the same in frequency as the ventricular pulsations. The left auricle ceased to contract seven minutes after death. The right ventricle was punctured with the needle of an aspirator, and its contents removed, whereupon the contractions became much stronger.

8	minutes	after	death,	ventricles	contracted	44	times	a minute.
10	"	"	"	"	"	30	"	"
12	"	"	"	"	"	16	"	"
18	"	"	"	"	"	16	"	"
29	"	"	"	"	"	6	"	"

Then all contractions ceased and could not be restored by any kind of irritation.

Right auricle ceased beating ten minutes after death, but commenced to contract again nineteen minutes later, contracting twenty-four times a minute, the movements becoming more rapid and at times irregular for forty-eight minutes after death.

Experiment 4. Dog, weight thirty-five pounds. Into the left carotid artery 60 c. cm. of air were injected in a proximal direction. The animal was seized at once with convulsions of a tetanic character, with the limbs extended

and rigid. Involuntary discharges from bowels and bladder. Sensation, motion, and reflex actions suspended. Pupils contracted. Respirations very rapid. Heart's action slow and labored. The left jugular vein was opened and four ounces of blood were abstracted, with the result of greatly improving the heart's action. Both vessels were ligated and the wound closed. The animal was in profound stupor, resembling complete anæthesia, until death occurred two hours and a half after the operation. Half an hour after the injection the pulse was seventy-four, respirations forty-four in a minute.

On opening the abdomen the large veins were found very much dilated and contained air. Large air bubbles were also found in the pulmonary, internal mammary, and coronary arteries. Small thrombi were found in many of the ultimate branches of the pulmonary artery. The right side of the heart was distended with spumous blood and air. The left ventricle was almost completely empty, the endocardial lining presenting many patches of subserous ecchymoses. Nearly all the vessels of the brain, and the longitudinal sinus contained air. Cerebral and meningeal vessels engorged with blood. The animal died with marked symptoms of asphyxia. The tetanic rigidity of the extremities and the muscles of the trunk, as well as the remaining prominent cerebral symptoms, were produced by the intense cerebral congestion, the result of obstruction of some of the smaller vessels by air-emboli.

Experiment 5. Adult dog, weight twenty pounds. Into the peripheral end of the right carotid artery 20 c. cm. of air were injected after the animal had completely recovered from the anæsthetic. The dog collapsed almost immediately and fell to the floor, perfectly unconscious, with extended and rigid limbs. Breathing exceedingly rapid, but gradually growing slower as consciousness returned. When the animal attempted to walk it staggered, and frequently fell, having apparently lost the power of co-ordination in the posterior extremities. The pupils, at first dilated, later became very much contracted. After about two hours, the animal walked without difficulty, but respiration, as well as the heart's action, continued very rapid. The next day complete recovery had taken place. Aside from the cerebral and spinal symptoms, the arterial embolism in this case resulted in no serious consequences; the most threatening symptoms were referable to venous embolism, showing that most of the air had passed through the capillaries into the venous circulation and right side of the heart.

Experiment 6. Adult dog, weight twenty-two pounds. Right carotid artery exposed and 45 c. cm. of air injected towards the heart. Involuntary discharges from bladder and rectum. Pupils dilated, later contracted. Animal completely unconscious, anterior limbs extended and rigid, slight opisthotonos, breathing mostly abdominal. Churning sounds over heart heard a few seconds after injection, disappeared after eight minutes. Respiration ceased five minutes after the air was injected, but was again restored by artificial respiration and faradization of vagus and diaphragm. Twenty-three minutes after the injection, pulse 128, respirations 24; fifty minutes after injection, pulse 105, respirations 26; fifty-two minutes after injection, pulse 120, respirations 20; ninety minutes after injection, pulse 180, respirations 20. At

this time the animal made several unsuccessful attempts to rise, but relapsed into a comatose state, which continued until death, which occurred fifteen hours after the operation.

At the post-mortem examination the arteries contained a good deal of dark, almost venous blood interspersed with bubbles of air. Air was found in the uterine, ovarian, iliac and mesenteric arteries and aorta; also in both venæ cavæ, pulmonary artery and veins. Some of the smallest branches of the pulmonary artery were obstructed by thrombi. Right ventricle distended with very dark, almost black, frothy blood. Left ventricle firmly contracted and almost empty. Left auricle contained dark, spumous blood. Coronary arteries distended with air; internal mammary arteries and veins also contained air. Air was found in all the cerebral vessels and sinuses, which were distended with dark fluid blood. Vessels of spinal cord were intensely congested and contained numerous air-bubbles. The mucous membrane of the stomach presented eleven points of extravasation, the largest being circular and one inch in diameter.

This case presented the most diffuse form of embolism, the emboli being found equally numerous and diffuse in the arterial and venous systems. The multiplicity and diffusion can be satisfactorily accounted for when we take into consideration the large amount of air which was injected, and the length of time which had elapsed from the time of insufflation until death occurred. The post-mortem appearances plainly indicated that death was produced by slow asphyxia. The primary unconsciousness and stupor were induced by the acute cerebral ischæmia; then a short period of consciousness returned, as soon as the collateral circulation in the brain had become partially established, when the animal became again comatose from carbonic acid intoxication. The abstraction of blood relieved the threatening symptoms attending the arterial embolism, but failed in preventing death from asphyxia by secondary venous embolism.

Experiment 7. Dog, weight twenty-six pounds. Injected 15 c. cm. of air into the right carotid artery in a peripheral direction. The animal had a slight convulsion and remained unconscious for about twenty minutes, when it rallied and was able to walk about the room with a slightly staggering gait. No complications followed the operation. In this instance the cerebral symptoms followed the insufflation instantly, but owing to the small amount of air injected, they were only of short duration; the air, passing the capillaries in a short time, entered the venuous circulation where it produced temporary disturbances in the pulmonary circulation.

Remarks.—Injection of air into arteries produces well-marked and characteristic symptoms which point directly to a disturbance in the circulation of the brain and spinal cord. The most prominent symptoms are: Convulsions, coma, tetanic rigidity of the limbs and extensor muscles of the back. The coma resembles complete and profound anæsthesia. These symptoms follow the operation

more quickly if the injection is made in a peripheral direction toward the brain. If the animal does not succumb to the primary effect of the air upon the brain and medulla oblongata, a series of symptoms succeed which announce the arrival of air in the veins and right side of the heart. All of the experiments show that it only requires a few seconds for the powerful contractions of the left ventricle to force at least a large portion of the air through the capillaries into the veins.

The primary effect of embolism of the vessels of the brain is to produce acute cerebral ischæmia, the intensity of which depends upon the number and size of the vessels which have become obstructed by the air-emboli. This anæmia soon gives rise to intense engorgement of the collateral vessels and the vessels behind the point of obstruction, an engorgement to such an extent that it often leads to rupture of capillary vessels and hæmorrhage into the paravascular tissues. Unless the amount of air injected is sufficient to prove rapidly fatal by causing suspension of the functions of the cerebro-spinal centers, the animal dies of asphyxia from embolism of the pulmonary artery, the same as though the air had been injected directly into the veins. The left ventricle, from its greater thickness and, in consequence, more powerful contractions (as compared with the right ventricle), is better adapted to overcome the increased resistance, and hence the air is rapidly forced through the systemic capillary circulation into the veins and right side of the heart. On this account an amount of air injected into arteries is not so dangerous as the same amount introduced directly into veins, as a certain percentage of it never reaches the veins and right side of the heart. Arterial air-embolism is attended by an additional source of danger, which consists in the greater tendency to coagulation of blood in the heart and vessels, as was noted in several experiments.

XIII. Direct Intra-Cardiac Insufflation of Air.

These experiments were made with a view of demonstrating by ocular inspection, that sudden over-distention of the cardiac muscles will arrest their contractility, and will thus produce paralysis of the heart in the diastole.

Experiment 1. Medium-sized cat. After the animal was fully under the influence of ether, respirations and heart's action being normal, the chest was rapidly opened and the heart exposed. Its movements remained regular.

From the sudden ingress of air into the cavity of the chest, the left lung collapsed, and it was found necessary, in order to prevent asphyxia, to make artificial respirations on the right side of the chest. The pericardium having been opened, the right ventricle was punctured with the needle of an aspirator, and air injected in sufficient quantity to distend the right chambers of the heart. which immediately ceased to contract. On emptying the right ventricle by withdrawing the air and blood, the rhythmic movements of the organ were restored. These manipulations were repeated at least half a dozen times, and always with the same uniform and constant results. Half an hour after opening the chest all movements of the heart ceased. The heart was now removed and immersed in water at a temperature of 105° F., when it again commenced to pulsate at the rate of 120 beats per minute. After the lapse of about two minutes it was removed from the warm water, still pulsating, and transferred to cold water, when all movements ceased instantaneously, and all efforts to revive them proved futile.

Experiment 2. Large Maltese cat. Heart exposed, right ventricle punctured, and 11 c. cm. of air injected, with the result of immediately arresting the pulsations of the right ventricle. When the air was withdrawn, the regular movements were renewed. This experiment was repeated on both ventricles eight or ten times in the course of half an hour with the same results. The auricles during all this time continued to contract. Ten minutes after the last puncture and evacuation the ventricles were still pulsating.

REMARKS.—Both of these observations support the statement that sudden over-distention of any of the cavities of the heart by inflation with air, will arrest its movements in the diastole, and that upon the removal of the increased intra-cardiac pressure, the movements of the organ are restored. It was found that by continuing the injecting force after the right ventricle had become distended, air could be forced readily through the pulmonary capillaries into the left side of the heart. In some instances one of the cavities of the heart was kept over-distended and at rest for at least a minute, and yet on removing its contents the rhythmic movements were resumed.

XIV. Aspiration of Right Ventricle for Air-Embolism.

Being satisfied of the fact that sudden over-distention of the right ventricle may and does produce paralysis in the diastole, it appeared reasonable to resort to some direct measure in removing the cause of over-distention in grave cases of venous air-embolism. Puncturing and aspiration of the right ventricle seemed to offer the best chances for accomplishing this object.

In the following experiments artificial, venous air-embolism was produced in the usual way, when the right ventricle was punctured with the needle of an aspirator two millimeters in diameter, and the contents of the right side of the heart removed by aspiration. The region over the heart was shaved and disinfected, and the exact point of puncture located before the animal was anæsthetized. The needle was always carefully disinfected by passing it through the flame of an alcohol lamp, and by immersion in carbolized water. When the puncture was made, the needle was advanced first only sufficiently deep to bury the opening in its point beneath the tissues, when a vacuum was created in the aspirator so that the entrance of the needle into the ventricle would be promptly announced by the escape of spumous blood. By following this precaution, additional injury to the heart, by pushing the needle further into the cavity of the ventricle, was avoided, and at the same time a prompt escape of blood was secured.

Experience taught me that it was very important not to push the needle too deeply into the cavity of the ventricle; not only for fear of inflicting additional injury to the endocardial lining opposite the point of entrance, but more particularly with a view of removing the free air which would naturally occupy the highest point in the cavity, if it was not intimately mixed with the blood. The needle was always directed obliquely from below upwards for the twofold purpose of making a valvular wound in the ventricle and of avoiding unnecessary injury to the endocardium.

Experiment 1. Dog, weight thirty-one pounds. 60 c. cm. of air were injected into the left jugular vein. The animal was seized immediately with a convulsion, followed by collapse. Heart's action tumultuous. Churning sounds over heart were distinctly perceptible. Respirations rapid and superficial. Right ventricle was punctured, and 120 c. cm. of spumous blood were withdrawn. Pulsations of heart became more feeble, and as respirations had ceased and could not be restored, the chest was opened. The right ventricle was found moderately dilated and still contracting. Slight contractions of lower portion of left auricle. Left ventricle contracted, but without motion. The needle of the aspirator was then introduced into the right auricle, which was distended and tympanitic. After emptying it, it commenced to contract. All contractions ceased half an hour after the air was introduced. Faradic currents had no effect upon the heart after it had ceased to contract. The pericardium contained air in considerable quantity, and about 4 c. cm. of fluid blood. Air was found in the right side of the heart, the left ventricle, coronary veins, and in the large veins in the immediate vicinity of the heart. Puncture

about an inch from septum, and nearly equidistant between the apex and base of heart. No injury of endocardium on opposite side.

Experiment 2. Sheep, weight ninety-five pounds. Before operation respirations 86, pulse 140. Injected 150 c. cm. of air into left jugular vein, which was immediately followed by convulsions and involuntary discharges. Aspiration of right ventricle and removal of 150 c. cm. of spumous blood. As the animal still presented an asphyxiated appearance, the ligature was removed from the distal end of the jugular vein, and about 120 c. cm. of blood were allowed to escape. The animal showed no signs of improvement, and died five minutes after the injection was made, having made only five attempts at respiration during the time.

Pericardium contained a small coagulum and a few bubbles of air. Right ventricle, distended and tympanitic, contained spumous blood. Two punctures were found over the middle of the right ventricle about one-half cm. apart; the second was made during the convulsive movements of the animal, which necessitated a partial withdrawal and reintroduction of the needle. On the inner surface each puncture was hermetically sealed by a minute thrombus which projected only very slightly into the cavity of the ventricle. No injury of opposite wall of ventricle. In the left ventricle, which was firmly contracted and empty, a small filiform coagulum projected through the aortic orifice into the aorta.

Experiment 3. Old dog, weight forty pounds. Injected 45 c. cm. of air into left jugular vein. Churning sounds over heart loud and distinct. Heart's action labored; respirations exceedingly rapid. No convulsions, but profound coma and involuntary discharges. A little more than one minute elapsed between the introduction of air and aspiration, during which time the heart's action became more and more embarrassed, and all of the symptoms became so grave, that death seemed unavoidable. But as the needle reached the heart, a slight impulse was imparted to it by the feeble pulsations, and 120 c. cm. of air and spumous blood were removed. The heart's action improved immediately, but the dyspnœa, although less severe, was still quite prominent. Consequently an additional 120 c. cm. of blood were allowed to flow from the peripheral extremity of the jugular vein, which promptly relieved the urgent symptoms. Ten minutes after the injection, respirations were 240 per minute; four minutes later 360, and after eight minutes more, 120. After forty minutes the stupor disappeared and the animal was able to walk. One hour after the operation, respirations were 20 and pulse 160 per minute. At this time the animal walked home—a distance of nearly two miles —and subsequently suffered no inconvenience from the operation.

Experiment 4. Dog, weight seventy-five pounds. Injected into left jugular vein 90 c. cm. of air, which produced intense difficulty in breathing and profound stupor. Sensation and reflex movements suspended. Heart's action exceedingly feeble and rapid. Churning sounds distinct. The aspirator and needle were kept in readiness to be used promptly on the approach of symptoms indicative of impending death. Two minutes after the injection the animal was apparently in a dying condition, upon which the needle was

plunged into the right ventricle, and from its rapid oscillations it was apparent that the heart's action had not entirely ceased, but was very rapid and feeble. As quickly as possible 180 c. cm. of spumous blood were withdrawn, which promptly relieved the most urgent symptoms; but as the respirations still remained rapid and labored, the ligature was removed from the distal end of the jugular vein, and 240 c. cm. of blood were allowed to escape. Eight minutes after the injection, the churning sounds over the heart were still present, but faint. Respirations 144; pulse 130. When the animal had recovered from the immediate effects of the operation, it was noticed that the posterior extremities could be moved only with difficulty, the gait being slow and staggering. For twelve hours the animal was dull and stupid, remaining in the same place without change of position. The drowsiness continued for thirty-six hours, after which the animal became lively, and went on to complete recovery without any further interruption. In this case it was apparent that the animal would have died from the large volume of air which had been injected, but for timely use of the needle and aspirator. Three weeks after the experiment the animal, being in perfect health, was killed by an arterial injection of air. No signs of pericarditis, endocarditis, or myocarditis. Puncture in ventricle indicated by a minute faint cicatrix.

Experiment 5. Old dog, weight twenty-five pounds. In this case the aspirator was used a few seconds after the insufflation of air was made, and the result shows how important it is to withdraw the air from the ventricle before it has had time to escape into the pulmonary artery. Immediately after the injection of 90 c. cm. of air into the left jugular vein, the animal became comatose. Respiration exceedingly rapid and heart's action imperceptible. The right ventricle was punctured at once and as soon as a part of its contents had been removed, the impulse of the heart was imparted to the needle, which could be distinctly seen and felt. Spumous blood and air to the amount of 150 c. cm. were withdrawn. The dog rallied rapidly after the aspiration, being able to walk in less than half an hour. He manifested no pain or discomfort from the air-embolism or operation. The volume of air in this case was three times as large as in the previous experiment, when the weight of the animals is compared. The immediate effects of the air were expended upon the heart, as was made evident by the temporary cessation of its pulsations, and yet death was prevented by the prompt removal of the excessive intra-cardiac pressure. The recovery was more rapid than in the previous cases, from the fact that not so much air had passed into the pulmonary artery, and that more was removed by aspiration. Two weeks later, the animal being in perfect health, 60 c. cm. of air were injected into the right jugular vein, which produced death in a few minutes, showing conclusively that the recovery after the first insufflation was due to the aspiration. Cicatrix of puncture plainly visible. No signs of inflammation in the pericardium, endocardium, or substance of the heart.

Experiment 6. Young dog, weight twenty-eight pounds. In this experiment 120 c. cm. of air were thrown into the left jugular vein in divided doses of 30 c. cm. each, in rapid succession. During the third injection the animal

howled and became comatose, and immediately after the last injection the heart's action ceased and respirations were reduced to a few irregular gasps. The right ventricle was punctured and 120 c. cm. of spumous blood and air were withdrawn, without producing any effect upon the heart. Artificial respiration was resorted to without any better result. The chest was opened at once. The pericardium contained 4 c. cm. of dark, venous blood and a few air bubbles. Right auricle continued to contract forty-eight times per minute. Left auricle and ventricle were distended and contained spumous blood. The needle had punctured the right auricle instead of the ventricle. All muscles, voluntary and involuntary, reacted promptly to the faradic current, but it had not the slightest effect upon the heart.

Experiment 7. Young dog, weight ten pounds. Injected 45 c. cm. of air into the left jugular vein. At the end of injection the dog howled, and the heart's action ceased almost instantaneously. The right ventricle was aspirated and 60 c. cm. of spumous blood were withdrawn. Artificial respiration was performed and the faradic current was applied, when the dog made a few ineffectual attempts at respiration before he died. On examination the pericardium was found to contain a slight amount of dark fluid blood and a few air-bubbles. Both auricles contracted about forty-eight times in a minute. Right ventricle arrested in diastole. Puncture was found near base of ventricle. Right ventricle was again aspirated, and the faradic current was applied directly to the heart and the needle, without producing the slightest effect. Right ventricle and pulmonary artery contained spumous blood. Left ventricle contracted and nearly empty.

Experiment 8. Adult dog, weight twenty-four pounds. Before operation, respirations 80; pulse 100 in a minute. Injection of 30 c. cm. of air into left jugular vein. Immediately after injection great restlessness, dyspnœa, and tumultuous action of heart. Churning sounds loud and distinct. Removed 90 c. cm. of spumous blood from right ventricle by aspiration. After the aspiration the improvement in respiration and pulse was marked. Recovery complete, and not attended by any complications.

Experiment 9. Same animal as in experiment 3. Animal in perfect health; time since first operation, three weeks. Injection of 40 c. cm. of air into right jugular vein. Symptoms the same as before. At the end of three minutes and a half the pulsations of the heart ceased, and the respirations were nearly suspended. The right ventricle was now punctured and 250 c. cm. of spumous blood were removed. No motion imparted to needle. Faradization and artificial respiration were ineffectual in restoring either the heart's action or respiration. On examination 30 c. cm. of dark fluid blood were found in the pericardium. No evidences of inflammation from former puncture. Right ventricle moderately distended with a clot of spumous blood. Point of second puncture one-half inch from coronary artery. The location of first puncture was marked near the base of the right ventricle by a faint minute cicatrix upon the pericardial surface, while the endocardium at a corresponding point showed an old circumscribed spot of ecchymosis, but no evidences of inflammation. Left ventricle contained no air

and only a minute quantity of fluid blood. Both auricles nearly empty. Pulmonary artery contained air and spumous blood.

This experiment demonstrates positively and conclusively the value of early aspiration of the right ventricle in venous air-embolism, where death is threatened by over-distention of the right side of the heart, or by asphyxia. In the former experiment a larger amount of air was injected, but the animal was saved by an early aspiration, by which a large amount of air was removed before it had had time to accumulate in the pulmonary artery. It also illustrates the utter uselessness of resorting to any kind of mechanical interference after a fatal dose of air has once passed beyond the semilunar valves into the pulmonary artery. In such instances the air has passed beyond our reach, and will inevitably lead to a fatal result by asphyxia.

Experiment 10. Adult dog, weight eighteen pounds. Injection of 60 c. cm. of air into left jugular vein. Immediate collapse; churning sounds distinct. Aspiration of 100 c. cm. of air and spumous blood from right ventricle. Three minutes after the insufflation, respiration and heart's action had ceased. No air or blood found in the pericardium. Needle puncture equidistant between base and apex of right ventricle, and about 2 cm. from septum. Right auricle contracting feebly 40 times a minute. Right ventricle dilated, fibrillary contractions at apex only; right ventricle and pulmonary artery contained spumous blood. Left auricle and ventricle contained only a slight amount of fluid blood and a few air bubbles.

Remarks.—These experiments serve to illustrate the following interesting points in pathology and surgery: 1. The heart can be punctured with a perfectly aseptic, medium-sized aspirator needle without any great immediate or remote danger. 2. Aspiration of the right ventricle for venous air-embolism, when done early enough (before a fatal dose of air has been forced into the pulmonary artery), must be considered in the light of a life-saving operation.

Although the needle used in all of these experiments was two millimeters in diameter, the hæmorrhage into the pericardium was never sufficient in quantity to prove a source of danger. The largest quantity found was 30 c. cm. (in experiment 9). In a number of cases no trace of blood was found in the pericardium. Against my expectations the same observations were made in regard to air. In one case the pericardium contained about 60 c. cm. of air, while in most cases only a few isolated air-bubbles were seen, while in others no trace of it could be found.

In all cases where the animal survived the operation and was killed from a few days to three weeks subsequently, no trace of inflammation could be found either in serous membranes, muscular tissue, or adjacent organs. Even adhesion between the parietal

and visceral layers of the pericardium at the point of puncture never occurred. The point of puncture was usually marked by a faint minute cicatrix in the visceral pericardium, unaccompanied by any pathological changes in the substance of the heart. We must take it for granted that if effusion of blood or air occurred in the pericardium in the animals which recovered, these adventitious substances caused no irritation, but were promptly removed by absorption.

With the exception of the subject of experiment 8, it may be safely assumed that all of the animals would have died had aspiration not been performed, so that the operation saved at least three of the animals out of ten, the whole number of experiments. The most conclusive proof of this statement was furnished by the subjects of experiments 3 and 5, as these animals died during subsequent experiments, from the introduction of a smaller quantity of air.

The question naturally arises: Why were not all of the animals saved by the aspiration? In reply it may be stated that the amount of air injected in most instances was large, more than was necessary to produce a fatal result. Another element of failure consisted in the postponement of the aspiration until a fatal dose of air had passed beyond the reach of the aspirator. To prevent death by air-embolism, it is essential to remove the air from the right ventricle as soon as possible after its entrance, before a fatal embolism of the pulmonary artery has had time to take place. In some of the experiments a fatal result might probably have been prevented by removing a larger quantity of air and blood with the aspirator, as in some instances the condition of the animal was improved by a subsequent venesection from the jugular vein.

XV. Catheterization and Aspiration of Right Auricle for Venous Air-Embolism.

In grave cases of accidental air-embolism it would be a desideratum to be in possession of some means, by which the air could be removed directly from the right side of the heart in the shortest possible space of time and with the simplest instrument. An aspirator is not always at hand, and is less frequently in a proper condition to be used on such short notice. It appeared to me that, inasmuch as the accidental introduction of air usually takes place through

wounds in one of the jugular veins, a catheter might be introduced through the wound into the vein, and from there passed directly into the heart, and the air and spumous blood withdrawn through it by aspiration. A catheter is almost always at hand, and its introduction would require only a few moments of time. The following experiments were made to test the feasibility of this procedure:

Experiment 1. Adult dog, weight twenty-four pounds. The right jugular vein was opened and 60 c. cm. of air were introduced in the usual way. The breathing became very difficult and the heart's action labored. The animal was comatose, pupils dilated. As soon as it could be done, a No. 6 English scale, gum elastic catheter, which had previously been made aseptic, was introduced into the wound, and passed into the heart, a distance of 15 cm., and with an exhausting syringe 250 c. cm. of air and spumous blood were removed. The animal recovered rapidly from the immediate effects of the air-embolism and operation, and subsequently manifested no symptoms of disease.

Experiment 2. Young dog, weight thirty pounds. Injected 100 c. cm. of air into left jugular vein. The heart's action ceased almost instantaneously. The same catheter was introduced and pushed forward a distance of 18 cm., and about 120 c. cm. of air and spumous blood withdrawn by the mouth. At this time respiration ceased, and as no pulsations of the heart could be felt, the chest was opened at once. Fibrillary contractions of right ventricle, which was distended and tympanitic. Left auricle and ventricle contracted and motionless. Right auricle contracted regularly 80 times a minute. Faradic and galvanic currents had no effect on ventricles. Right auricle responded to a slowly interrupted galvanic current.

The catheter was again introduced, and its course observed as it entered the right auricle. It was found impossible by any manipulation to pass it from the auricle into the ventricle. In every instance it passed from the right auricle directly into the inferior vena cava. The right side of the heart was filled with water to test the possibility of removing fluids from the right auricle without introduction of the catheter into the chamber. A catheter with an open extremity was used. No amount of suction force succeeded in removing any of the fluid, until the open end of the catheter reached the auricle, when both chambers could be readily emptied. As long as the end of the catheter remained in the vein, the walls of the vein in front of the catheter would invariably collapse and close the opening in the catheter completely on applying suction force.

This satisfied me that in order to remove air or blood from the right side of the heart, it is necessary to introduce the catheter as far as the auricle. It was also evident that in case the catheter was introduced too far, its distal end would pass into the inferior vena cava, and on aspiration only venous blood would be withdrawn, not air and spumous blood from the right chambers of the heart, for the removal of which the procedure was intended. On opening the right side of the heart, a large spongy clot of spumous blood was found in the right auricle, which extended for some distance into the ventricle. Left ven-

tricle contained only a small amount of fluid blood and a few air-bubbles. As the heart's action had ceased before catheterization, death was undoubtedly due to the insufflation of air and not to the formation of a thrombus in the heart.

Experiment 3. Adult dog, weight twenty pounds. Injected 30 c. cm. of air into right jugular vein. Catheterization and aspiration of right auricle, by which 90 c. cm. of air and spumous blood had been withdrawn, when catheter became impermeable from a thrombus in its interior and was removed. Before emptying the right side of the heart the animal was comatose; breathing and heart's action exceedingly rapid. After aspiration, rapid improvement and complete recovery. If the catheter in this instance had been permitted to remain louger in the auricle, the thrombus which formed in the interior of the instrument would undoubtedly have increased rapidly, and would have extended to the auricle, in which event death from thrombosis would have been unavoidable.

Experiment 4. Old dog, weight forty pounds. Before operation respirations 16; pulse 100 per minute. Injection of 90 c. cm. of air into left jugular vein. Passed a No. 5 Nélaton's catheter into right auricle, a distance of 27 cm., and removed 250 c. cm. of air and spumous blood. Immediately after the insufflation the animal uttered a howl and became comatose. Pulse 250 per minute, respirations so rapid that they could not be counted. Seven minutes after catheterization heart's action very irregular, tumultuous, and about three hundred beats per minute. Two minutes later respiration ceased, after which the heart's action became slow and feeble, and ceased a few seconds later. Internal mammary aud coronary veins filled with air. Left side of heart contaiued a small amount of bright red, frothy blood. Right ventricle moderately dilated, showed fibrillary contractions. Superior and inferior vena cava, right auricle and ventricle contained a continuous, soft thrombus, the oldest portion of which corresponded to the superior veua cava. The upper portion of the clot in the inferior vena cava contained air. Death in this instance was due to the formation of a thrombus.

Experiment 5. Adult dog, weight twenty-five pounds. Injection of 60 c. cm. of air into left jugular vein produced immediate collapse, distressing dyspnœa, and great rapidity aud irregularity of heart's action. The dog howled when the heart's action ceased, and respiration became gaspiug. Some delay was experienced in the introduction of the catheter, and when the instrument was iu place all signs of life had disappeared. About 50 c. cm. of spumous blood were withdrawn without any signs of improvement. Artificial respiratiou aud faradizatiou were resorted to without producing the slightest impression. On opening the chest it was observed that the right auricle contracted about 30 times a minute. Irregular fibrillary contractions of apex of right ventricle. Right side of heart moderately distended with spumous blood. No thrombus. Left veutricle almost empty.

Experiment 6. Adult dog, weight fifteen pounds. Injection of 60 c. cm. of air into right jugular vein. In this case the catheter was connected with a rubber-tube three feet in length, which was kept under water; after which the

instrument was pushed along the jugular vein into the right auricle. The injection of air was followed by the most urgent and distressing symptoms. Only a small amount of dark venous blood escaped through the rubber-tube until the catheter reached the right auricle, when a gush of spumous blood escaped from the tube under water. As the blood did not continue to escape, about 60 c. cm. of spumous blood were withdrawn. After the aspiration the symptoms improved rapidly, and within twenty-five minutes, with the exception of a slight excess in the respiratory movements, the animal appeared to be perfectly well. The ultimate recovery was complete and was not disturbed by any complications.

Experiment 7. Adult dog, weight forty-eight pounds. Before operation pulse 150; respirations 28. Injection of 120 c. cm. of air into right jugular vein. The animal howled and collapsed. Respirations increased at once to 100 per minute. Heart's action tumultuous, and churning sounds loud and distinct. Passed a Nélaton's catheter into the right auricle, and aspirated 360 c. cm. of air and spumous blood. No signs of improvement followed, and in fifteen minutes the animal was dead. At the post-mortem examination the internal mammary veins were found distended with air. Right side of heart tympanitic and distended. Slight fibrillary contractions of right auricle. Apex of right ventricle contracted regularly 22 times in a minute. Coronary veins filled with air. A thrombus had formed, which extended from the superior vena cava into the right auricle, ventricle, and for a distance of 25 cm. into the inferior vena cava. Pulmonary artery contained no thrombus, but was distended with air and spumous blood. Left ventricle contracted; contained a small amount of fluid blood and air-bubbles. It was quite evident that the thrombus had primarily formed around the catheter, and that by new additions it had finally reached the distal portion of the inferior vena cava. Death was produced by thrombosis.

REMARKS.—The therapeutical value of catheterization and aspiration of the right auricle for air-embolism is made apparent by the following tabular arrangement of the experiments:

No. of experiment.	Weight of animal.	Amount of air injected.	Amount of air and blood removed.	Result.	Cause of death.
1	24 pounds.	60 c. cm.	250 c. cm.	Recovery.	
2	30 "	100 "	120 "	Death.	Thrombosis.
3	20 "	30 "	90 "	Recovery.	
4	40 "	90 "	250 "	Death.	Thrombosis.
5	25 "	60 "	50 "	"	Air-embolism.
6	15 "	60 "	60 "	Recovery.	
7	48 "	120 "	360 "	Death.	Thrombosis.

From this table it will be seen that of seven animals subjected to the operation, three recovered and four died. The amount of air injected in the subjects of experiments 1 and 6 was sufficient to

destroy life, so that we can safely assume that the animals would have died, but for the speedy resort to catheterization and aspiration. In the subject of experiment 3, recovery might have taken place without the operation, as the relative quantity of air was much smaller. In the four fatal cases death was produced only once from the presence of air, while the direct cause of death in the remaining three cases was thrombosis. All possible precautions were exercised to prevent this accident. The catheter was made aseptic by thorough cleansing and immersion in a five per cent. solution of carbolic acid. Before the operation the instrument was kept ready for use in an alkaline solution, of the temperature of the body, and yet this accident happened in three out of seven cases.

It is now asserted that the introduction of aseptic bodies into the circulation does not give rise to thrombosis, and it may be possible that some of the instruments used, in spite of the pains taken to render them aseptic, were still not in a fit condition to be used for such a purpose. Catheterization and aspiration of the right auricle for air-embolism compare favorably with puncture and aspiration of the right ventricle as a life-saving procedure, but the former operation is more dangerous on account of the tendency to the formation of a thrombus within or around the catheter. If this formation of thrombus could be avoided with certainty, catheterization and aspiration of the right auricle would recommend itself as the most expedient and reliable therapeutic agent in cases where life is threatened by air-embolism.

XVI. Prophylactic Treatment of Air-Embolism.

As clinical experience and experimental research have shown that the admission of air into veins is not an infrequent occurrence and has often resulted in death, it is the duty of the surgeon in extirpating tumors which are in close proximity to the large veins within the area of the "danger zone," to resort to measures which will prevent the ingress of air in case a vein is accidentally wounded. The following precautionary means deserve consideration: 1. Position. 2. Compression. 3. Ligature. 4. Aseptic tampon.

1. Position.

Regular respiratory movements of the chest are necessary to maintain the equilibrium between the arterial and venous circulation,

and should always be secured in operating in close proximity to veins at the base of the neck; as during a sudden deep inspiration, the direct aspiratory effect of respiration in the veins extends to some distance, constituting thus the direct cause of entrance of air into an open vein. Before anæsthetics were used, Poisenille advised that the patient should be instructed not to make any deep inspiratory movements during the operation. At the present time the same object is better obtained by keeping the patient thoroughly and continuously under the influence of the anæsthetic. Gerdy aimed to prevent the aspiratory effect of respiration by recommending compression of the thorax, but the advice is more useful in theory than in practice, as suspension of the thoracic movements for any length of time, would necessarily interfere with respiration and cause death by asphyxia.

The venous circulation is greatly influenced by position. In the elevated position the blood gravitates towards the heart and the veins are emptied. If, while in this position, a vein is wounded, and the walls of the vessel do not collapse on account of some anatomical peculiarities, or from rigidity of the vein wall itself, due to pathological changes, a vacuum is formed and air enters. The entrance of air into a vein distended with blood is a physical impossibility. In reading the clinical histories of cases where air entered veins during operations, we are met by the fact that in almost all of the cases, the wounding of the vein was not followed by any considerable loss of blood, and we are usually told that the air entered almost immediately after the vessel was injured, which would indicate that the vein was empty or nearly so at the time it was wounded. In a number of cases the bloodless condition of the vein attracted the attention of the operator, and is particularly emphasized in the description of the cases. As long as the interior of a vein and the lumen of a wound in its walls are occupied by a continuous stream of blood there is no danger that air will be admitted.

Statistics tend to show that the accidental admission of air into veins was more frequent before anæsthetics were used, a fact which we can only explain by assuming that the patients were then usually placed in a sitting or semi-recumbent position during the operation, positions favorable to the return of venous blood from the cervical region. On the other hand, the safe administration of an anæsthetic

necessitates the horizontal position, in which the veins of the neck become distended with blood. In the former instance, the return of venous blood in the vessels of the upper portion of the body was favored by the elevated position, and the vacuity thus produced in the veins constituted the most important and potent factor in determining the entrance of air. In the horizontal position, the veins of the neck are never empty, and to effect entrance of air the exciting cause must operate with increased intensity. On this account the horizontal or dependent position of the region of the body to be operated upon, recommends itself as the simplest prophylactic measure against the accidental entrance of air into wounded veins. This position increases the risk of hæmorrhage from the injured vein, but this accident in its immediate effects is less disastrous to the patient and more readily under the control of the surgeon than air-embolism.

2. Compression.

Compression of a vein between the seat of operation and the heart, for the purpose of guarding against the entrance of air, may be divided into intermediate and direct. Intermediate compression is only applicable in cases where the external jugular vein is in danger of being wounded. If the tumor to be extirpated is not located too low in the region of the neck, uninterrupted digital compression of the external jugular vein just above the clavicle can be relied upon to prevent entrance of air through this vessel. The internal jugular and axillary veins are so deeply situated that intermediate digital compression cannot be relied upon in the prevention of air-embolism, consequently direct compression should be resorted to whenever it becomes necessary to guard against this accident. Warren recommended that, in the extirpation of tumors which are in close proximity to the large veins of the neck and axilla, the separation of the pedicle should be reserved until the last, in order to enable the operator to compress the vein between the seat of operation and the heart more effectually, should the vessel be injured during the operation.

Langenbeck advised that the vein on the distal and proximal sides of the tumor should be exposed to view as a preliminary measure before attempting the removal of the tumor, in order to facilitate direct compression in case the vessel should be opened during the dissection. The adoption of either of these precautions

would successfully prevent a second ingress of air, but would not protect the patient against the dangers arising from the first dose. Permanent central compression augments the danger of wounding the vein, from the turgidity of the vessel which it produces, while distal compression would be attended by the same risk, only in an opposite way, by rendering the vessel empty and consequently more difficult of recognition. If the attachments of the tumor to the vein are of such a nature that they can be separated without great danger of injuring the vessel, then the vein should be isolated on the proximal side and the vessel compressed with a hæmostatic forceps, which will afford greater safety than digital compression; at the same time the field of operation is not obscured and narrowed by the fingers and hand of the assistant, an item of great importance in operating in the regions of the neck or axillary space.

Injury of the vein in such instances will be promptly announced by hæmorrhage from the distal portion, but the entrance of air into the right ventricle is made impossible by the prophylactic compression of the vessel between the seat of operation and the heart. Should the vein be wounded, any further ill effects arising from this accident can be prevented by applying a lateral ligature, or by tying both ends of the vein according to the size of the wound, before removing the compressing forceps. In all operations where any of the large veins are in danger of being wounded, the position of the parts should be such as to retain as nearly as possible their normal anatomical relations. The operator should make haste slowly, and identify every structure before using cutting instruments. In extirpating tumors that are deeply situated, the external incision should always be large, so as to afford free access to the base or deepest portion of the growth to be removed. A pair of Billroth's retractors will do good service during the deep dissection.

Hæmorrhage must be carefully arrested as it occurs, in order to enable the surgeon to see what he is doing. Isolation of the vein from the tumor must be accomplished by the use of blunt instruments, and all firmer attachments should be carefully examined and identified before using the knife or scissors. As it is usually impossible, or, at any rate, impracticable to find the vein in the tumor or its immediate vicinity, the rule should always be followed to expose the vessel for some distance from the tumor on the proximal side,

and then follow it by carefully separating the attached tissues by means of blunt instruments.

Under antiseptic precautions the jugular vein can be isolated for a great distance without fear of compromising the vitality of its tissues or causing thrombosis. When a tumor is attached to the jugular vein it is a dangerous practice to make traction on the tumor for the purpose of facilitating the deep dissection, as this procedure will disturb the normal anatomical relations of the vessel, and thus expose it to greater risk of being wounded. Free access to the base of the tumor must be secured without displacing the subjacent vein. As soon as the tumor has been isolated from the surrounding tissues, a thorough examination should be made of the extent of its base and its relations to the subjacent vein before proceeding any further with the dissection.

If the conclusion is reached that the vein is so intimately connected with the base of the tumor that it is in great danger of being injured during the further progress of the extirpation, it becomes necessary to resort to direct compression of the distal and proximal portions of the vein. By isolating and compressing the vein on each side of the tumor, both excessive turgidity and emptiness of the intervening portion of the vein are avoided. The amount of blood in the vein between the two points of compression can be regulated, and only a sufficient quantity allowed to remain to indicate the exact location of the vessel. Compression is again made with hæmostatic forceps. After the complete removal of the tumor, the forceps on the distal side of the vein is removed first, in order to test the integrity of the vessel and with a view to prevent any possibility of the entrance of air. If no hæmorrhage takes place we may be satisfied that the vein has not been injured, and the remaining pair of forceps can be safely removed. In such cases the exposed portion of the vein should always be covered with the adjacent tissues by deep sutures *en étages* of catgut before closing the wound.

If the vein has been wounded, a lateral ligature is applied, or both ends are ligated after complete division of the vessel, before the forceps between the vein wound and the heart is removed. By following this plan we accomplish the following objects: 1. Hæmorrhage from the injured vein is slight and perfectly under the control of the surgeon. 2. Absolute security against the entrance of air. 3. A more thorough removal of the tumor.

3. Ligature.

In all cases where a large vein passes through the substance of the tumor and where isolation of the vessel appears inexpedient or impossible, double ligation recommends itself as the safest prophylactic measure against both hæmorrhage and air-embolism. As soon as the base of the tumor is reached, the vein is exposed on each side and tied with catgut, and the intervening portion is extirpated with the tumor. By adopting this plan we secure for the patient absolute protection against hæmorrhage and air-embolism. Adequate collateral circulation is established in a short time, so that ligation or excision of the internal jugular or axillary veins can be done under antiseptic precautions without danger of causing serious disturbance of the cerebral circulation in the former, or gangrene of the arm in the latter instance. Isolation and ligation of the vein on the proximal side of the tumor should always be resorted to, when injury to the vein is unavoidable.

In case the prophylactic ligation of the vein on the distal side of the tumor is rendered difficult or impossible by existing circumstances, the following course can be pursued: After ligation of the vein on the proximal side of the tumor, a hæmostatic forceps is applied a little distance from the ligature on the side of the tumor, and the vessel is divided between the forceps and the ligature. The ligature prevents the entrance of air, and the forceps serves the purpose of a temporary hæmostatic agent during the extirpation of the tumor. The base of the tumor, with the vein, is detached when the vessel on the distal side of the tumor is sought for and tied, and the remaining attachments of the tumor, including the vein, are cut. This plan affords protection against the entrance of air, but during the separation of the tumor hæmorrhage may occur from accidental wounds of the distal portion of the vein; which, however, can be readily controlled by compression with hæmostatic forceps until the vessel is permanently secured on the distal side of the tumor.

4. Aseptic Tampon.

If a large vein has been wounded, which from its location is inaccessible to the ligature, permanent compression with a graduated aseptic tampon will arrest the hæmorrhage and prevent further ingress of air.

XVII. Operative Treatment of Air-Embolism.

Considering the infrequency of air-embolism as compared with the number of wounds of the vein, it is not surprising to find that, as a rule, surgical writers have little, if anything, to say on the subject of the prevention and treatment of air-embolism. It must be apparent to all, that in following the rules laid down when we considered the prophylactic treatment, the accidental introduction of air into veins is prevented almost to a certainty, and that they will also furnish a safe guide in the prevention and management of venous hæmorrhage when operating within the area of the "danger zone." If the preventive treatment is carefully carried out, air-embolism will become one of the rarest accidents in surgery.

As even with the greatest care an accident of this kind might happen, it becomes necessary to allude to the operative treatment of air-embolism. The occurrence of the accident is sometimes announced by an audible hissing or sucking sound, and is always followed almost instantly by a well-marked train of distressing symptoms which are directly referable to a mechanical obstruction to the circulation in the right side of the heart and the pulmonary artery. The treatment must depend on the quantity of air which has entered, and the severity of the symptoms produced by it. The therapeutic measures should be aimed towards meeting the following indications: 1. Prevention of further ingress of air. 2. Administration of cardiac stimulants to sustain the action of the heart. 3. Venesection to relieve intravenous pressure. 4. Aspiration of air from the right side of the heart to prevent over-distention and paralysis of right ventricle.

1. Prevention of Further Ingress of Air.

When air has entered through a gaping wound in a vein during inspiration, there is great danger that the same occurrence will repeat itself during successive respiratory movements of the chest, hence the first object of treatment consists in closing the wound in the vein. This is most quickly done by digital compression, which is continued until the vein has been rendered impermeable by ligature or permanent compression. If the symptoms are urgent no time should be lost in securing the vessel until the patient has rallied from the immediate effects of the air-embolism. It is also necessary

to postpone the permanent closure of the vein until the time has elapsed for any indications to arise which would call for venesection or operative removal of the air from the right side of the heart, as in such cases it might become necessary to utilize the wounded vein as a route for the introduction of a catheter into the heart.

When the time has arrived for closing the vein, the finger should not be removed suddenly from the vessel, for fear of causing a repetition of the accident; it should remain *in situ* until the vessel can be compressed on the proximal side of the vein wound by an assistant. The exact location of the wound will now be probably indicated by escape of blood from the distal end of the vein, when the vessel can be seized with a forceps, and after its isolation, a double ligature applied. If it is found impossible to ligate the vein, then the vessel is compressed in the wound by means of a graduated aseptic tampon, retained in place by uninterrupted pressure, until definitive closure of the wound has taken place.

2. Cardiac Stimulation.

The heart's action must be supported by position and by the use of cardiac stimulants, which are best administered subcutaneously and by inhalation. The patient must be placed in the horizontal position in order to guard as much as possible against the occurrence of cerebral anæmia, as well as to lessen the intravascular pressure to a minimum. If the quantity of air admitted is not sufficient to produce instant death by paralysis of the right side of the heart in the diastole, the symptoms which follow always point towards an embarrassment of the circulation in the right side of the heart and the pulmonary artery, which are always accompanied by dyspnœa, combined with evidences indicating the existence of acute cerebral ischæmia.

If death does not take place within a few minutes from obstruction to the circulation through the pulmonary artery by the presence of air in that vessel, then the contractions of the right ventricle will force at least a part of the air through the pulmonary capillaries into the general circulation, thus preventing death by asphyxia. As soon as the air-embolism of the pulmonary artery has been relieved, the most urgent symptoms subside, as the air-emboli in the arterial system are distributed over a larger area and consequently produce an embolism of lesser extent and gravity in more distant and less

essential organs. The safety of the patient depends on the capacity of the right ventricle to force the air through the pulmonary into the general circulation, in other words, upon the time which is required to remove the emboli from the pulmonary artery into the systemic circulation.

Nitrite of amyl, from its stimulating properties upon the heart and from the rapidity of its action, would recommend itself in the form of inhalation as the most efficient drug in preventing threatened syncope. The temporary dilatation of the small blood-vessels would tend to produce, at least for a short time, a diminution of the intravascular pressure. Hypodermic injections of camphor and alcohol, although slower in their action, would also assist in antagonizing the deleterious effect of over-distention of the right ventricle by the air-embolus. In all of my experiments where electricity was used, it had no effect whatever upon the heart, even when applied directly to the organ, hence it would be of no use to resort to this agent for the purpose of sustaining or re-establishing the movements of this organ in serious cases of air-embolism.

3. Venesection.

In all post-mortem examinations after sudden death from air-embolism two constant pathological conditions are always found present: 1. A comparatively empty state of the left side of the heart and throughout the entire arterial system. 2. Distention of the right ventricle and intense engorgement of the whole venous system. Both of these conditions are, of course, due to the presence of air in the ultimate branches of the pulmonary artery, which prevents the free transit of the venous blood through the pulmonary capillaries into the left side of the heart. As a direct result of these conditions, we have a diminution of the intravascular pressure in the left side of the heart and the arteries, and a corresponding increase in the right side of the heart and the veins. The immediate and greatest danger arises from an accumulation of air and blood in the right side of the heart, to such an extent as to arrest the ventricular contractions by over-distention before the equilibrium between the arterial and venous circulation can be restored by the removal of the air-emboli from the pulmonary artery into the general circulation.

Even the most extreme antagonists to the lancet must acknowledge the benefit which follows its use in similar obstructions of the

circulation caused by other pathological conditions. In severe cases of pneumonia where the circulation has been so much obstructed that death is threatened by venous engorgement and over-distention of the right ventricle, the free use of the lancet is the safest and most efficient means in equalizing the circulation, as by the abstraction of blood from one of the veins, the intravascular pressure in the veins and right side of the heart is diminished in the promptest and most direct manner. As the adventitious air in the pulmonary capillaries can and will be forced into the general circulation by the contractions of the right ventricle, and as the urgent symptoms will subside after this has taken place, it is of paramount importance to gain time by protecting the right ventricle against an undue amount of additional labor.

Among the indirect remedies to accomplish this object venesection deserves the first place. I could refer to a number of the experiments where copious bleeding from the distal portion of the open vein was promptly followed by improvement in all the symptoms. Vulpian asserted that, after insufflation of air into veins, the contractions of the heart were restored after the organ had ceased pulsating, by the abstraction of blood from the sinuses of the brain and the veins of the neck. I have never succeeded in restoring the action of the heart, after its pulsations had ceased completely, by any kind of treatment; but, when the contractions have become imperfect from this cause, I know that removal of the cause of over-distention will restore the force and efficiency of the contractions.

H. Fischer[1] sarcastically alludes to this valuable agent in the treatment of air-embolism as a remedy from which only homœopaths would expect to derive any benefit. An expression of this kind concerning such a valuable remedy, and in this particular connection, must be looked upon as unscientific and contrary to well-established clinical and pathological facts. I must, therefore, insist that venesection from the distal end of the wounded vein will prove beneficial in all cases of air-embolism where venous engorgement and over-distention of the right ventricle constitute elements of imminent danger. If practicable, the bleeding should always be done from the distal end of the wounded vein, while the proximal end is compressed or ligated. The advantages of doing so are obvious for the

[1] Ueber die Gefahren des Lufteintritts in die Venen, p. 17.

following reasons: 1. The abstraction of blood is accomplished in the shortest possible space of time. 2. The blood escapes in a large stream from a capacious vessel. 3. No additional instruments are required, and the infliction of another wound is obviated.

4. Aspiration of Air from the Heart.

Clinical experience and experimental research teach us that when a certain amount of air enters the right side of the heart, death invariably takes place in a very short time and cannot be prevented by any of the indirect methods of treatment. It seems to me that in such cases it would be legitimate and proper for the surgeon to resort to some procedure by which the air could be removed directly from the heart. To accomplish this object Fischer recommends that forcible expiratory movements should be excited by inducing coughing, sneezing, or vomiting, with a view that during the forcible compression of the thorax the aspirated air would be forced out through the wound in the vein. Against this advice the following objections may be entered:

1. The difficulty or impossibility of exciting coughing, sneezing, vomiting, or any other act on the part of the patient when in a condition of collapse.

2. If during the forcible compression of the chest, the air is forced backwards, it will be just as likely to pass into other veins than the one through which it entered.

3. The difficulty of preventing the admission of more air during the forcible inspiration following the forcible expiration.

4. During prolonged forcible expiration the intra-vascular pressure in the veins and right side of the heart is greatly increased, thus constituting an additional source of immediate danger.

5. Forcible expiratory movements of the thorax, by compressing the heart, will be more likely to force the air onward with the venous current into the pulmonary artery, where it will do the most harm by causing asphyxia from a sudden and extensive air-embolism in that vessel.

The only direct means of removing air from the heart consist in puncture of the right ventricle and catheterization of the right auricle combined with aspiration. The experiments made by myself in this direction have demonstrated that puncture of the right ventricle with an aseptic needle two millimeters in diameter is in

itself a harmless procedure. When we remember that in the human subject the heart has often been the seat of more extensive injury without any immediate or remote ill effects, we must abandon the idea that slight injuries of this organ are necessarily fatal. Small aseptic wounds of the heart heal rapidly, and in the same manner as in any other organ of the body.

In the preceding experiments the hearts were removed from dogs a few days to three weeks after puncture; and not in a single specimen are we able to detect any evidences of organic changes, either in the substance of the organ or its serous membranes. In most of the specimens the point of puncture was marked by a minute cicatrix, visible upon the surface of the visceral pericardium. In penetrating wounds of the heart, hæmorrhage into the pericardium and compression of the heart from this cause are to be feared, and constitute the only source of immediate danger. There is no plausible reason why in the human subject an oblique puncture of the right ventricle should be followed by more hæmorrhage than in animals, and consequently I have no hesitation in recommending puncture and aspiration of the heart as a justifiable procedure in cases of air-embolism which would otherwise necessarily prove fatal.

The question naturally arises: What symptoms indicate a resort to puncture and aspiration of the right ventricle? Two different conditions, as far as time and symptoms are concerned, may call for this operation. The puncture should be made as soon as possible after the entrance of air, in the event that the primary effect of the heart embolus has produced sudden over-distention and paralysis of the right ventricle, an occurrence which would be indicated by immediate collapse and partial or complete suspension of the heart's action. In such a case the direct withdrawal of air from the right ventricle, as soon as possible after its entrance, affords the only possible hope of restoring the pulsations of the heart, by removing the cause of the mechanical over-distention.

In the second class of cases the patient has collapsed, but the heart has withstood the primary effect of the aspirated air. The heart's action is rapid and tumultuous, perhaps at times intermittent. The ear applied over the cardiac region detects distinct churning sounds. Respirations are rapid, and all symptoms point towards imperfect circulation and aëration of the blood as expressed by the pallid face and blue lips. Some of the air has passed from the

right side of the heart into the pulmonary artery, and from the obstruction of the circulation through this vessel, the right ventricle becomes more and more distended, the contractions therefore becoming less perfect and more frequent. At this stage, puncture and aspiration of the right ventricle will overcome the most urgent symptoms by the removal of air and spumous blood, and enough time may be gained for the right ventricle to force the remaining air-emboli through the pulmonary capillaries into the general circulation, and the life of the patient is saved.

These are the cases where puncture and aspiration of the right ventricle can be done with a fair prospect of not only relieving urgent symptoms, but of ultimate recovery. They are also more favorable from the fact that more time is afforded the surgeon in procuring and using the aspirator. The puncture should always be made in an oblique direction, from below upwards, so as to make a valvular tract in the heart for the purpose of preventing hæmorrhage into the pericardium, and also for giving the point of the needle a direction in which it is least likely to injure the opposite endocardial lining. The left intercostal space, between the fourth and fifth ribs, about an inch and one-half from the margin of the sternum, is selected as the best point for making the puncture. The needle, thoroughly disinfected, is connected with the aspirator, and, as soon as its point is buried in the tissues, a vacuum is created in the aspirator, and the needle is advanced slowly until spumous blood is felt and seen to escape, when it is firmly held in this position, and the contents of the ventricle are withdrawn as quickly as possible. My experiments have satisfied me that I generally removed the needle too soon, not having withdrawn a sufficient quantity of blood and air. In some of the experiments I followed the aspiration by blood-letting with marked benefit. Removal of the same quantity of blood directly from the right ventricle would have been productive of more good, as less air would have been left in the heart.

The experiments on dogs have shown that these animals will always recover if the quantity of air injected into the veins does not exceed one c. cm. of air to each pound of its weight. Double this quantity must be considered a fatal dose. If, therefore, we can remove by aspiration only a portion of air directly from the right ventricle, we may be able to maintain the action of the heart and respiration until the embolism of the pulmonary artery has been

relieved by the passage of air from this vessel into the general circulation. When the presence of a foreign body in any other part of the body threatens to destroy life, no surgeon would hesitate to make an attempt to remove it, even if the effort should be attended by an increase of the immediate risk.

Air in the right side of the heart acts the part of a foreign body, and, when it destroys life, it does so by causing mechanical obstruction to the circulation. The timely removal of the air is the only rational treatment in all cases where simpler measures have proved inadequate in preventing a fatal termination. An aspirator in good condition should be on hand in every well-regulated hospital, and of ready access in cases of emergency. If air-embolism occurs during an operation, the instrument should be used before the heart has ceased pulsating, when prompt action on the part of the operator may obviate death in an otherwise hopeless case.

The experiments on catheterization of the heart were undertaken with a view to simplify the operative removal of air from the right side of the heart. An aseptic catheter was introduced into the wounded vein and passed into the right auricle, and by aspiration air and spumous blood were removed. The result showed that some of the animals were saved from impending death by this simple procedure. The great danger attending this operation consisted in the tendency of the blood to coagulate within or around the distal end of the catheter, and death from the formation of a thrombus in the large veins and right side of the heart. If the formation of a thrombus could in some way be prevented with certainty, catheterization and aspiration of the heart would recommend itself as the simplest and safest measure in the operative treatment of air-embolism.

Catheterization of the heart is not a new suggestion, as the introduction of a tube into the heart for the same purpose was recommended more than fifty years ago by Magendie. I should recommend the adoption of this procedure only when the air has entered through a wound in the internal jugular, and when the symptoms leave no doubt that death would be inevitable without direct removal of the air by aspiration. An aseptic Nélaton's catheter with an open end should be introduced into the wound through which the air entered, and pushed as quickly as possible as far as the auricle, when the air and spumous blood can be withdrawn by the

mouth in the absence of any other means of aspiration. Admission of more air is prevented by compression of the distal end of the instrument before and between the aspirations. The whole operation must be done as quickly as possible for the purpose of preventing coagulation of the blood. For the same reason an instrument of large calibre should be used.

In presenting the practical outcome of my experimental work in the form of these few suggestions on the operative treatment of air-embolism, I am fully aware that it may be said that my labor has been in vain, and that the means suggested do not admit of application in practice. In reply, I will say that desperate cases call for desperate measures. When death stares us in the face we have not only a right, but it becomes our most imperative duty to resort to any plan of treatment which holds out the slightest hope of saving the life of the patient.

For myself I am fully convinced of the safety and usefulness of puncture and aspiration of the right ventricle in grave cases of air-embolism, where simpler means have proved of no avail. When no aspirator is within reach, I also believe in the propriety of catheterization and aspiration of the heart as a last resort in all cases of air-embolism where death would surely take place without it. If by the adoption of either of these methods of direct treatment of air-embolism a single human life should be saved, I shall feel amply rewarded for the labor incurred in the preparation of this paper.

XVIII. Summary.

1. The presence of adventitious air in the vascular system during life gives rise to air-embolism.

2. Each air-embolus constitutes a mechanical source of partial or complete obstruction to the flow of blood in the vessel in which it is located.

3. Aspiration during the inspiratory movements of the chest is the direct or exciting cause of ingress of air into a wounded vein or sinus.

4. Elevation of the head is the sole predisposing cause of the entrance of air in wounds of the superior longitudinal sinus.

5. In veins the predisposing causes consist in:

a. Elevation of the part wounded.

b. Pathological or anatomical conditions which prevent collapse of the vein when it is wounded.

6. Insufflation of a fatal quantity of air into a vein produces death by:

a. Mechanical over-distention of the right ventricle of the heart, and paralysis in the diastole.

b. Asphyxia from obstruction to the pulmonary circulation consequent upon embolism of the pulmonary artery.

7. Insufflation of a quantity of air into the arteries is less dangerous than when the same quantity is introduced into veins. When death is produced in this manner it results from:

a. Acute cerebral ischæmia.

b. Secondary venous air-embolism.

c. Intense collateral engorgement of the vessels of the brain and spinal cord.

The manner of death is determined by the amount of air injected, and the direction in which the injection is thrown, as well as by the time which has elapsed between the operation and the fatal termination.

8. Air injected into arteries is readily forced through the systemic capillaries into the venous circulation and right side of the heart by the powerful contractions of the left ventricle.

9. Air-embolism of the pulmonary artery is relieved in a comparatively short time, provided the contractions of the right ventricle continue unimpaired for a sufficient length of time to force the air through the pulmonary capillaries into the general circulation.

10. The prophylactic treatment consists in proximal or double compression or ligation of the vein which is endangered by the operation.

11. The indirect treatment has for its objects:

a. Prevention of admission of air.

b. Administration by inhalation or hypodermic injection of cardiac stimulants.

c. Venesection.

12. The direct or operative treatment by:

a. Puncture and aspiration of the right ventricle.

b. Catheterization and aspiration of the right auricle, which are proposed with a view to obviate the direct cause of death by the removal of air and spumous blood, thus relieving directly the over-distention of the right ventricle, and, at the same time, to guard against a fatal embolism of the pulmonary artery.

13. The results obtained by experiments on animals warrant the adoption of the operative treatment of air-embolism in practice, as a last resort, in all cases where the indirect treatment has proved inadequate to meet the urgent indications.

THE SURGERY OF THE PANCREAS, AS BASED UPON EXPERIMENTS AND CLINICAL RESEARCHES.[1]

In the following article, an attempt will be made to lay the foundations for a rational method of treatment of some of the injuries and diseases of the pancreas by direct surgical measures. The literature on the surgery of the pancreas is exceedingly scanty and loosely scattered through the medical journals and text-books, as no previous attempt has been made to arrange the material in a systematic form for ready reference. Our present knowledge of the surgical treatment of diseases of the pancreas is limited to a few operations performed for the cure of retention cysts, by excision or the formation of an external pancreatic fistula. The clinical material which I have collected, and more particularly the description of pathological conditions found within and around the pancreas at post-mortem examinations, will be utilized for the purpose of pointing out new indications for operative interference, by such methods as will suggest themselves from the results obtained by experiments upon animals.

I. Comparative Anatomy of the Pancreas.

A few words on the comparative anatomy of the pancreas are necessary in order to compare the results obtained by certain experiments with similar conditions when observed in the human subject as the result of traumatism or pathological changes. In some of the higher invertebrates certain organs connected with the alimentary canal have received the name of pancreas; but they have done so rather from their position and inferred function than from any certain evidence of their use, or from their anatomical structure.[2] If they exist, they consist of simple cæcal appendages attached to the upper part of the intestine.

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[1] Read before the American Surgical Association, 1886.

[2] Cyclopædia of Anatomy and Surgery, vol. v. p. 90.

In the osseous fishes, certain cæca or blind tubes may be seen at the commencement of the intestinal canal, close to the pylorus, which from their position have received the name of pyloric appendages, and have been regarded by most anatomists as the analogue of the pancreas in higher animals. In reptiles, we make a greater approach to the structure of the pancreas of higher animals, both in form and structure. In the frog the pancreas is shaped not unlike that of the human subject, but its broad end is in the opposite direction. It is in close approximation with the duodenum in its whole length. A proper duct cannot be found; probably small ducts from different parts of the gland open into the biliary duct as it passes through the gland. The pancreas of birds is proportionately larger than in any other animal. The gland has always more than one, usually two or three ducts, which open by separate orifices and often at some considerable distance from one another.

The chief differences between the pancreas in other mammalia and in man relate merely to its color, its consistence, its degree of lobulation, its form, its volume, its union into a single mass or its separation into two distinct parts, and, lastly, its position and relations with different portions of the peritoneum.

Its form is generally more or less that of a narrow band, divisible into two portions: one, the duodenal, following the curvature of the duodenum, and placed vertically or obliquely; the other, the gastrosplenic, extending transversely, and therefore opposite the other, from the duodenum to the spleen, against which it rests; the latter is always developed, the former is often defective or absent, and must be considered merely as an accessory portion.

In the carnivora the pancreas is always large in proportion to the size of the animal. In the ox, from the distinctness of the two portions, the organ has a bilobar appearance. In the horse, from the gastrosplenic portion being doubled, it has a trilobar form. In the rodents, the organ is spread out in an arborescent manner in an extensive mesentery that imparts free movement to the long duodenum, and extends to the left in a sort of omentum which underlies the stomach. In the rabbit, the duct enters the intestine nine inches or a foot from the pylorus.

In the mammalia, as in man, there is usually but one pancreatic duct, which enters the intestine near the pylorus, although sometimes a great way removed from it. There are, however, considerable

varieties of insertion. In the lion, two pancreatic ducts join the common bile-duct separately, one near the other. In the dog, I have made the observation that the ducts from both portions of the pancreas unite near the duodenum or within its wall, and that the orifice of the common pancreatic duct is usually located about an inch or two below the opening of the bile-duct. If an accessory duct exists, it usually opens into the intestine at a point in common with the bile-duct.

Berard and Colin[1] have shown that the pancreas is not connected with the duodenum in young dogs. It consists originally of two parts, of which one lies parallel to the duodenum (caudex inferior), and the other perpendicular (caudex superior). These two portions join later to form a mass which becomes adherent to the duodenum. Each portion has its own duct, which afterward join to enter the intestine about two and a half centimeters below the opening of the bile-duct. Sometimes there is a second duct arising from either portion, or more rarely from both, which enters the duodenum by the side of the bile-duct.

The pancreas of the pig has usually only one duct, but when two exist, the second smaller duct communicates with the principal duct, which opens into the common bile-duct.

The irregular distribution and insertion of the pancreatic duct in mammalia and the frequency with which a second and third duct is found, are important to remember in connection with experiments on the pancreas, by intercepting the secretion by ligation of the duct; as it is exceedingly difficult if not impossible to ascertain the existence or absence of the small accessory ducts, and on this account it would be impossible to prove that all of the outlets of the gland had been intercepted, even if more than one duct had been found and ligated.

II. Development of the Pancreas.

Remak[2] has studied the development of the pancreas in the young chick. He found that the matrix could be seen somewhat later than that of the liver—about sixty-five hours after incubation had commenced. It consists primarily of a bulging of the hypoblast

[1] Canstatt's Jahresbericht, 1857, 1–3, p. 64.

[2] Entwickelung der Wirbelthiere, Berlin, 1855, pp. 54, 115, 164.

of the posterior wall of the intestinal tube, covered by a thickened prolongation of the connective tissue layer of the bowel. (Fig. 1).

The embryonal pancreas shows in the beginning a cavity which is in communication with the open lumen of the bowel. The changes which take place in the embryonal pancreas during the first five days can be readily observed and are easily understood.

From the thick wall of the hypoblast, numerous small, solid lobules spring, while the hollow space in communication with the bowel assumes more and more the shape of a canal. The connective tissue layer does not increase in size in the same degree, and presents no lobular projections upon its surface. On this account the

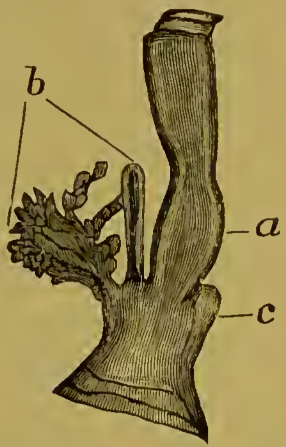

Fig. 1. Embryo of chick, four days old.

a. Stomach.
b. Liver and bile-ducts.
c. Pancreas.

new organ has assumed a pyriform shape externally; on the other hand, the glandular portion in the connective tissue layer takes on a branched structure. (Fig. 2.)

The hypoblastic layer is the basis of the parenchyma. Composed of cells, the connective tissue layer serves as the basis for the vascular constituents of the gland. The embryonal connective tissue disappears during the development of the gland in proportion as the cellular portion increases, until, finally, only enough connective tissue is left to serve as a nidus for the vessels and as a membrana propria of the acini.

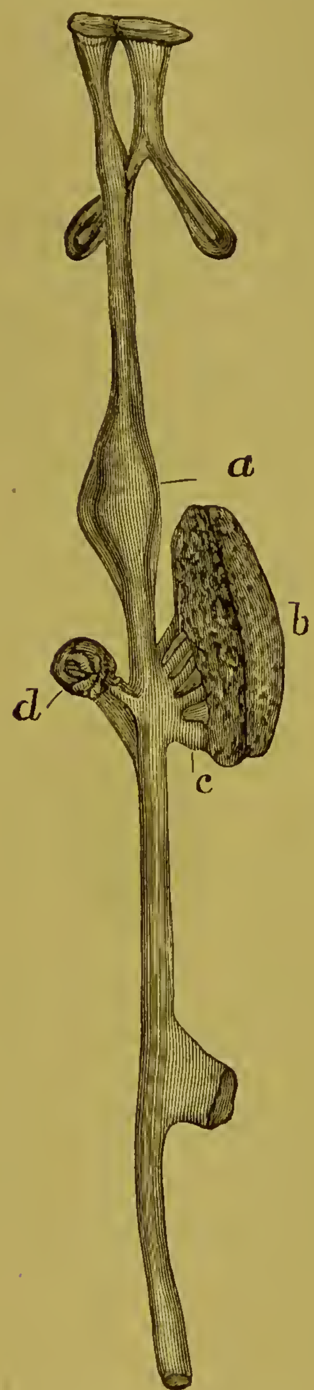

FIG. 2. Embryo of chick, five days old.

a. Stomach.
b. Liver and bile-duct.
c. Gall-bladder.
d. Pancreas.

The pancreas is not developed by symmetrical folding of both walls of the intestinal canal, but each wall grows by proliferation in different degrees to form the pancreas. The excavation in the rudimentary gland does not exist at first, but the original and essential structures are the cellular parenchyma of the gland from the epithelial lining of the intestine, and the vessel- and nerve-enveloping layer of connective tissue. As the pancreas in birds has two ducts, the question arose how the second duct was formed. The most plausible explanation was afforded by the assumption that the primary duct divides itself into two in a longitudinal direction.

Remak, in 1846, found another explanation by examining two geese, between three and four weeks old. He found two ducts at a

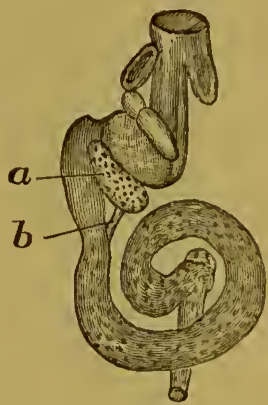

FIG. 3. Larva of frog.

a. Pancreas.
b. Pancreatic duct.

short distance from each other, in connection with the wall of the intestine. A closer examination showed, however, that only one of the ducts, the upper, was in communication with the lumen of the intestine; the other presented a blind pouch adherent to the wall of the intestine.

From this, it may be concluded that the second duct springs from the first, and, at a later period, a new communication with the bowel is established at a point corresponding to its cæcal extremity. He has since observed the same condition in the larvæ of frogs. (Fig. 3.)

It appears then established that the first and primary duct of

the pancreas is found in the rudimentary organ, and is from the beginning in communication with the bowel; while any additional ducts, whether normal or anomalous, originate in the substance of the gland and are only secondarily brought in communication with the bowel by a process of atrophy and absorption between the cæcal extremity of the duct and the intestinal wall. The existence of anomalous ducts communicating with one of the principal ducts and the intestine can be explained in a similar manner. Thus, in dogs, it is uncommon to find a small duct in the gastrosplenic half of the gland, connecting the intestine at a point where the common bile-duct opens into the intestine, with the common duct, as illustrated in figure 17.

It is apparent that in cases of this kind obliteration of the common duct on the distal side of the anomalous or accessory duct would not interfere with the normal evacuation of the secretion into the intestinal canal. The occurrence of an accessory pancreas can only be explained by the assumption that during the growth of the rudimentary pancreas, certain portions of the secreting structure become isolated by constriction and displacement, and that such portions of the gland are brought into communication with the intestinal canal by the development of an accessory duct.

III. Physiology of the Pancreas.

A brief consideration of the most important functions of the pancreas becomes necessary in connection with our subject, as it will serve to furnish an interpretation of some of the symptoms observed in such affections of the pancreas as interfere with the normal secretion or outflow of the pancreatic juice.

Claude Bernard, in 1848, discovered the most important function of the pancreatic juice, by observing that it exerted an emulsifying effect upon all kinds of fat. He found that by mixing fresh pancreatic juice with oil, lard, butter, or tallow, and keeping the mixture at a temperature of 35° to 40° C., an emulsion formed almost immediately.[1] Saliva, gastric juice, bile, and blood-serum do not produce this effect. The emulsifying process takes place by the division of fat into minute globules by the pancreatic juice, without converting it into a new chemical compound. The organic principle

[1] Schleiden and Froriep's Neue Notizen, vol. vii., No. 136, pp. 55, 56.

in the juice which possesses this property is very easily decomposed and precipitated by heat. Bile, with pancreatic juice, dissolves neutral as well as acid fats.

Bernard ligated both pancreatic ducts in dogs, and the single duct in rabbits, and fed the animals on fat. The fat was found unchanged in the intestinal canal and the lacteals were empty. Fatty diarrhœa has been observed in a number of cases where the pancreas was the seat of extensive lesions, and the presence of this symptom should always lead the physician to make special search for additional symptoms confirming the suspicion of the existence of disease of the pancreas.

There is no dispute among physiologists in regard to the action of pancreatic juice in transforming starch into sugar. This function was first observed by Valentin, in 1844, who experimented with an artificial fluid made by infusing pieces of pancreas in water. Bouchardat and Sankras first observed this property in the normal pancreatic secretion. The property of converting starch into sugar is possessed also by the saliva and intestinal juice; it therefore becomes an important question to determine the effect of a defective pancreatic secretion in cases where there is imperfect digestion of starchy food. It seems that cane sugar is transformed into glucose almost exclusively by the action of the pancreatic juice.

This fact has received confirmation in the case of intestinal fistula observed by Busch. The fistula was located in the lower portion of the small intestine. When cane sugar was introduced in quantity into the stomach, fasting, the fluid which escaped from the upper end of the intestine contained a small quantity of glucose, but never any cane sugar. Cane sugar introduced into the fistula so that it would pass along only the lower end of the bowel, was not converted into glucose, but a large portion of it was found in the fæces as cane sugar. In cases of suspected organic lesions of the pancreas it would, therefore, appear advisable to resort to feeding with cane sugar and subsequent examination of the stools for undigested cane sugar, as a diagnostic measure. The presence of cane sugar in the stools would indicate that little or no pancreatic juice was being secreted.

The last function of the pancreas consists in converting, with the aid of the bile and intestinal juice, the albuminoids, such as gluten, fibrin, albumen, casein, and musculine into albuminose or

peptones. This latter effect of the pancreas has been doubted by a number of German physiologists, but the fact seems to be demonstrated by experiment as well as by the circumstance that the pancreas is larger in carnivorous than in herbivorous animals.

Schiff has found that the physiological function of the pancreas is at its maximum about nine hours after the ingestion of food, and at its minimum about four to six hours later. During the greatest activity of the gland the vessels become more turgid, and can be seen with the aid of a lens between and upon the lobules, while during a state of rest they are seen only between the lobules. During digestion the gland presents a pale red color, while during rest it appears grayish-white.

The influence of the nerve-centers upon the pancreas has been made a subject of careful study by Schiff.[1] Section of both pneumogastric nerves has no effect upon the circulation or secretion of the pancreas. Animals subjected to this experiment readily digested dextrine or peptones introduced into the stomach; but if ordinary food was given, no secretion took place, as stomach digestion was suspended. Total destruction of the three semilunar ganglia of the sympathetic arrests completely the secretory functions of the pancreas, even if the most favorable conditions are established by the introduction of food or injection of the products of digestion into the stomach. Wounding of these ganglia, short of total destruction, does not produce the same effect.

Injury of the spinal cord, on a level with the eighth, ninth, or tenth rib, does not interfere in the least with stomach digestion, but promptly arrests all secretion from the pancreas, which cannot be excited by food nor by the presence of dextrine in the stomach. Heidenhain has ascertained that stimulation of the medulla oblongata increases the flow of pancreatic juice as well as its active constituents. These experiments show that the reflex action of the stomach upon the pancreas is not transmitted through the sympathetic, but through the spinal cord.

That the essential active principle of the pancreatic juice is necessary for digestion, has been shown by Corvisart, who found that in dogs the pancreatic juice contained, nine and a half hours after a meal, no ferment which was capable of dissolving albuminous sub-

[1] Canstatt's Jahresbericht, 1861, 1-3, p. 119.

stances. If, however, the animal was made to fast for a longer time than this, the ferment was again produced in some unknown manner. Pancreatic digestion becomes apparent six or seven hours after a meal, the time being somewhat dependent upon the duration of digestion.

The present views concerning the action of the pancreatic juice in the process of digestion may be summarized as follows:

1. Starch is converted by a diastatic ferment into dextrine and sugar, a continuation of the action of the saliva in the intestine.

2. Melted and fluid fats are emulsified by it (a property which has been assigned in a less degree to bile); at the same time, glycerine and fatty acids are formed during the process. The emulsifying process is aided by the fatty acids and alkaline salts which effect saponification (Brücke, Gad, Quincke).

3. Albuminoid substances and glue-containing tissues, when mixed with an alkaline solution, are dissolved and converted into peptones independently of stomach digestion (Corvisart). A portion of the peptones undergoes still further changes: in the case of albuminoid substances, leucin, tyrosin, xanthin, and sarcin; in the case of glue, tyrosin, glycin, and ammonium may appear.

Fresh pancreatic juice obtained from the duct of Wirsung is a clear, viscid, alkaline, highly putrescible fluid, of a specific gravity of 1.030, which solidifies completely on boiling. Pancreatic juice contains: 1, albumen; 2, a number of ferments; 3, salts, especially of soda; 4, water. Sometimes traces of self-digestion of the juice can be found, especially leucin (Herman).[1]

The pancreas secretes continually in herbivorous animals: in carnivorous, only during digestion (Heidenhain). The ferments are only present in the gland, trypsin only in a state of preparation, a so-called zymogen, which, on division, yields trypsin: this division takes place on exposure of the gland to air, the action of oxygen, very dilute alkalies, acids, alcohol, etc. During secretion the cells of the lobules are enlarged while the latter become swollen; at the same time the vessels are considerably dilated.

The exact quantity of pancreatic juice secreted in man and most animals is unknown. From a practical point of view, it is important to allude to the effect of the pancreatic juice upon the skin.

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[1] Lehrbuch der Physiologie. Berlin, 1882. p. 107.

which it macerates, so that when the fluid remains in contact with the skin for any length of time it becomes irritated and presents a raw, eczematous surface. It also appears that the same effect is not produced when it is brought in contact with the peritoneum, because in this locality fresh pancreatic juice is removed rapidly by absorption. A positive diagnosis of disease of the pancreas will only become possible when more attention shall have been bestowed upon the symptoms arising from defective digestion, the result of a defective or faulty function of the pancreas—a pancreatic indigestion. Long-continued indigestion of fatty or starchy food should be considered a sufficient indication for instituting a most careful search for pancreatic disease, by ascertaining the effect upon the digestion of particular articles of diet, and by examining with care the discharges from the bowels.

IV. Experiments on the Pancreas.

The operative treatment of injuries and diseases of the pancreas belongs to the future. Until now, the efforts of surgeons have been limited to the treatment of a few cases of cysts of the pancreas. The results obtained in these cases have been so encouraging, that undoubtedly other lesions of this organ will soon constitute new indications for surgical treatment.

The clinical material that is now available is inadequate to furnish a reliable basis for new operations; on this account it has been my object to obtain new light by subjecting the pancreas to a variety of surgical procedures, to ascertain the tolerance of this organ to direct treatment, and to determine, if possible, how much of the gland could be removed with safety in case it is the seat of injury or disease. The object of these experiments also included an attempt to elucidate the causes and pathological conditions of some of the well-recognized lesions of this organ.

Dogs and cats were used exclusively as subjects of these experiments, as a few trials soon satisfied me that in the smaller herbivora, as the rabbit and sheep, the pancreas was proportionately small and difficult of access. The operation was always performed under antiseptic precautions, with the exclusion of the spray, and the typical orthodox dressing. The abdomen was always shaved and disinfected with a solution of corrosive sublimate; ether was used as an anæs-

thetic. The abdominal incision was made through the linea alba, from near the tip of the xiphoid cartilage to the umbilicus.

The omentum major was either pushed upward, or, in the majority of cases, an opening was made into it by tearing at a point opposite the external incision. The guide to the pancreas was always the pyloric orifice of the stomach—after the index finger had reached this point, it was passed along the duodenum for three or four inches, when the bowel was grasped between the index finger and thumb and brought with the pancreas into the incision.

If any considerable prolapse of the viscera was made necessary to accomplish the object for which the operation was made, the exposed organs were carefully protected with a compress of gauze wrung out in a warm weak solution of corrosive sublimate (1: 2000). Irrigation of the external wound and protruded organs with the same solution was frequently resorted to, to cleanse the parts of blood, and to preserve the wound in an aseptic condition. A good light and an empty stomach facilitated the operation greatly.

It was always found difficult to detach the pancreas from the duodenum without incurring a considerable and often dangerous loss of blood. To prevent this occurrence most effectively, blunt dissection and direct compression with a moist, hot, aseptic sponge, proved the most effective measures; when large vessels were to be divided, double prophylactic ligation was often resorted to.

After completion of the operation the pancreas and duodenum were thoroughly cleansed and dried, and the toilet of the peritoneal cavity made with care; the abdominal incision was closed with interrupted sutures introduced in the usual manner so as to include the peritoneum. The external wound was sealed with a small compress of iodoform cotton repeatedly saturated with iodoform collodium. At the end of a week the sutures were removed. Primary union of the abdominal incision was the rule; in only a few instances healing of the wound was accomplished by granulation. Ventral hernia was observed in a number of cases.

1. Complete Section of the Pancreas.

Complete section of the pancreas was made an object of experimentation, to ascertain whether the continuity of the pancreatic duct would be restored after complete division and subsequent accurate coaptation, and to study the process of repair between the

divided ends of the pancreas. The section was made transversely, and, after arresting all hæmorrhage, the margins of the wound were brought into accurate contact with deep catgut sutures, which were made to embrace the entire thickness of the organ.

Experiment 1. Dog, four and one half months old; weight thirty-five pounds. Operation performed August 23, 1885. Complete division of pancreas transversely through the middle portion; vessels ligated with fine catgut, the hæmorrhage being arterial from the gastrosplenic, and venous from the duodenal end. Cut surfaces brought together accurately with fine catgut sutures, which were passed through the entire thickness of the organ, about one-third of an inch from the margins of the visceral wound. Animal

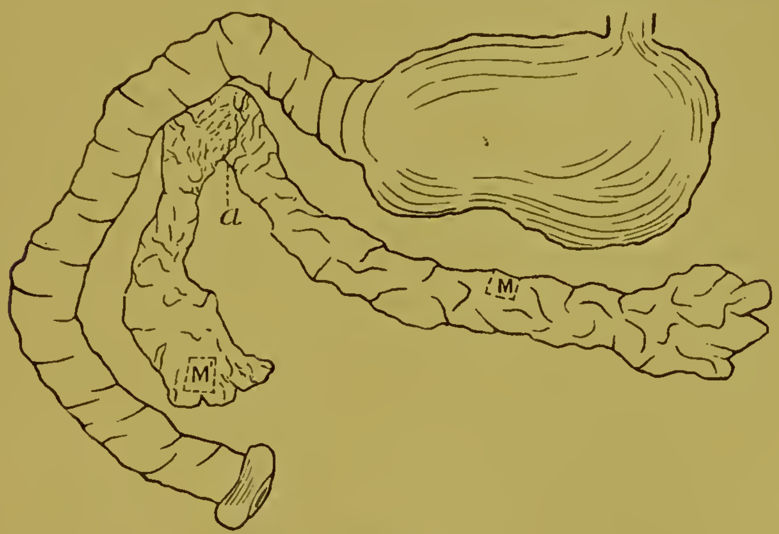

FIG. 4.

a. Point of section and coaptation by sutures.
Sections from M, gastrosplenic portion, show parenchyma cells in a state of fatty degeneration. Connective tissue increased.
Sections from M′, duodenal portion, show normal structure. At *a*, narrow band of cicatricial tissue.

showed no signs of suffering or disease after the operation, but lost four pounds in weight during the first eight days. After this time the animal began to increase in weight. Highest temperatnre 104° F., on the fourth day. The animal was killed December 6, 1885, one hundred and five days after the operation.

An examination of the pancreas showed that union had taken place between the two ends by means of a narrow cicatrix, which was indicated by a slight constriction at the site of section. Duodenal portion of gland presented a normal appearance, as the section had been made on the splenic side of the common duct. Gastrosplenic end somewhat atrophic and sclerosed.

Pancreatic duct patent to cicatrix, where the principal duct of the splenic portion was completely obliterated. No dilatation of duct in the splenic end. (Fig. 4.)

Experiment 2. Adult dog, medium size; complete section of pancreas through the junction of the middle with the splenic end. Only artery from splenic end required ligation. Immediate coaptation by means of three catgut ligatures passed through substance of gland. Animal remained well after the operation; appetite unimpaired. Dog was killed three weeks after the operation; abdominal wound completely healed; at point of section slight adhesions to neighboring organs. Visceral wound healed by a linear cicatrix of young connective tissue. Pancreatic duct completely obliterated at site of operation.

Remarks.—These operations would tend to show that complete division of the pancreas, when not complicated by other and more serious lesions, is not a dangerous accident, if the only source of danger, hæmorrhage, is met by proper surgical treatment. The coaptation of the divided ends would be desirable, but is not essential, as the continuity of the duct is not restored after this injury. No disturbance of digestion was observed in either case, as an adequate amount of pancreatic juice was secreted from the portion of the gland which remained in communication with the lumen of the intestine. As in both of these instances a greater or less amount of pancreatic juice must have escaped into the peritoneal cavity from the cut surfaces, and perhaps later from the divided duct of the splenic end, we have thus early evidence of the innocuity of extravasation of pancreatic juice into the peritoneal cavity. The process of repair was in both instances accomplished by the interposition of a linear cicatrix between the divided and coaptated ends.

Although accurate approximation was effected by three sutures, transfixing the entire thickness of the gland by passing the needle from before backward on one side, and from behind forward on the other, it seems that primary union between the divided ends failed to take place, and that the process of repair was accomplished by connective tissue proliferation from the connective tissue on the surface of the wound, a process necessarily accompanied by a simultaneous degeneration of the parenchyma of the gland, over an area corresponding to the seat of cicatrization.

Microscopical examination of sections made in close proximity to the cicatrix, showed various degrees of degenerative changes in the cells of the parenchyma, with a corresponding space of connective tissue proliferation.

Complete section of the duct, even when the ends are kept in accurate coaptation, appears to result uniformly in the obliteration of the duct at the site of section. The obliteration is the direct result of the formation of a cicatrix in the lumen of the duct from the cut surfaces. In both specimens the length of the cicatrix—consequently the extent of impermeability of the duct—corresponds to the length of the cicatrix interposed between the divided ends of the gland.

The practical deductions to be obtained from these experiments are: That in transverse visceral wounds of the pancreas, the most important indication that presents itself, is to arrest hæmorrhage by ligating the bleeding vessels, and to resort to suturing of the severed organ with a view to retain both ends of the pancreas as nearly as possible in their normal location, and thus maintain as nearly as possible the integrity of the vascular supply, rather than with the purpose of obtaining restoration of continuity of the divided pancreatic duct, which, if it could be accomplished, would preserve the physiological importance of the detached portion of the gland. By the detached portion of the gland, I mean that portion which no longer remains in physiological connection with the intestine, and which never regains its physiological importance after the duct has become obliterated by a cicatrix at the point of section.

2. Laceration of the Pancreas.

Having observed that complete section of the pancreas is followed by severe hæmorrhage, both arterial and venous, which undoubtedly might prove a source of no inconsiderable danger in cases of similar wounds of the organ in man, the following experiment was made to ascertain the extent of hæmorrhage after laceration of this organ, without the intervention of treatment:

Experiment. 3. Large adult cat; weight seven and one-half pounds. Abdomen opened through the median line, the pancreas exposed and detached sufficiently from the duodenum at the junction of the middle with the duodenal end, where it was torn completely across and the bleeding ends dropped into the abdominal cavity; the wound was closed in the usual manner.

The hæmorrhage was noticed to be much less than after section. Highest temperature 104.6° F., two days after operation. No symptoms of hæmorrhage or peritonitis. On the removal of the sutures the abdominal incision had apparently closed. Six days later the wound opened, and it was reported that one end of the pancreas had protruded from the wound. The prolapsed

viscus and wound were disinfected, the organ replaced, and the opening closed with sutures.

The animal did not appear to be very ill, but died two days later. At the autopsy no effusion was found in the peritoneal cavity and no signs of general peritonitis. A portion of the duodenum appeared gangrenous. The lacerated end of the splenic portion was adherent to the duodenum at a point two inches below the pyloric orifice of the stomach. The duodenal portion was very much atrophied and drawn up toward the splenic portion, and united to it by an extensive mass of cicatricial tissue. On opening the pancreatic duct from the duodenum, no communication could be found between it and the gastro-splenic portion of the gland.

Remarks.—Death in this case resulted from the accidental reopening of the abdominal wound. The prolapsed organ was, in all probability, the duodenum and not the pancreas; the gangrene of the intestine was undoubtedly caused by the prolapse and strangulation before the bowel was replaced. The laceration of the pancreas was made at a point where the two ducts meet; hence the impermeability of the duct in the gastro-splenic portion of the pancreas. Hæmorrhage was arrested spontaneously, and the process of repair, so far as the wound in the pancreas was concerned, appeared to be satisfactory. The divided ends were displaced considerably immediately after the laceration, but were subsequently brought into close contact by the cicatricial contraction.

3. Comminution of the Pancreas.

It has been asserted by a number of authorities that dead pancreatic tissue is a highly putrescible substance, and on this account its presence is very liable to serve as a source of infection.

Believing that putrefaction can never occur without the specific germs, even in the case of dead and highly putrescible substances, the following experiments were made to test the correctness of this assertion:

Experiment 4. Maltese cat; weight three and a quarter pounds. Operation September 18, 1885. The pancreas, with its vessels, was completely detached from the duodenum to the extent of two inches, about the middle of the gland. The isolated portion was completely crushed between the blades of a sequestrum forceps. No hæmorrhage whatever occurred, and the organ was dropped into the abdominal cavity. The day after the operation the temperature rose to 105° F., but the next day it was normal, and remained so until the killing of the animal, December 13, eighty-six days after the operation.

No evidences of diffuse peritonitis, only slight adhesions where the gland had been crushed. The duodenal portion was atrophied and drawn toward the gastrosplenic portion, to which it was united by a firm cicatrix, which united the two ends of the gland to the duodenum, thus completing the mesenteric attachment of the bowel. The cicatrix *a*, showed a line of pigmentation throughout its entire thickness. (Fig. 5.) The crushed portion of the gland had disappeared entirely by absorption, and its place was occupied by a firm cicatrix, which, by contraction, had approximated both portions of the gland. The crushing was done below the point of entrance of the pancreatic duct, which caused the atrophy of the duodenal portion, which was no longer in physiological connection with the duodenum.

Fig. 5.

a. Point where gland was crushed.

Sections from M show normal tissue.

Sections from M′ show fatty degeneration and sclerosis.

Experiment 5. Young cat; weight two and a half pounds. Pancreas brought into the abdominal incision, with a loop of the duodenum; without separating it from the bowel it was crushed at its middle to the extent of two inches, between the blades of a sequestrum forceps. No hæmorrhage followed the procedure, and the organ was dropped back into the abdominal cavity. The animal had been in a bad condition before the operation, and died seven days later. At the autopsy the abdominal incision was found closed. No peritonitis or effusion. Crushed portion showed no signs of suppuration, but appeared thicker and shorter than after the crushing; a change which was attributed to the infiltration of the dead tissue by leucocytes, and connective

tissue proliferation. The two ends of the gland were brought into closer contact by contraction of the recent cicatrix, which had also the effect of doubling the duodenum upon itself.

Remarks.—In both instances the crushed parenchyma of the organ was promptly removed by absorption, which seems, in this particular locality, to proceed with unusual activity, an occurrence which can only be explained by the assumption that the peritoneum is active in this process. No infection took place, and no evidence of putrefaction could be found. Should wound infection take place in cases of this kind, there can be no doubt that the dead pancreatic tissue would serve as a most favorable soil for the septic germs, and would thus create the most essential condition for the rapid and most dangerous form of infection.

These experiments also serve to demonstrate that subcutaneous crushing or comminution of the pancreas is in itself not a fatal or even dangerous injury. Subcutaneous comminution can only prove dangerous from the site of the injury, as, for instance, when the crushing takes place at or near the outlet of the pancreatic duct, where, from cicatricial contraction, obstruction of the duct takes place, which would interfere with the normal escape of pancreatic juice from the intact portion of the gland. If the comminuted tissue remains in an aseptic condition, it is removed by absorption, and the loss of substance is at least partially replaced by connective tissue, which forms a bridge between the intact portions of the gland. Subsequent degeneration, atrophy, and sclerosis take place in that portion of the gland which is no longer connected with the intestine by a permeable duct.

4. Complete Extirpation of the Pancreas.

A diversity of opinion still prevails among physiologists in regard to the immediate and remote effects of complete extirpation of the pancreas, or an artificial sudden suspension of its functions. The results obtained by different experimenters have led to diverse conclusions. Some claim for the pancreas an essential part in the process of digestion, while others affirm with equal positiveness that the gland can be removed or rendered physiologically incompetent without impairing digestion. Bernard[1] found that extirpation of

[1] Mémoire sur le Pancréas, p. 157.

the pancreas in birds produced death by marasmus in eight or ten days.

Berard and Colin removed the pancreas in a duck, and, on examining the animal six months later, found the site of the pancreas occupied by a thin layer of fat, which contained a few reddish nodules. No connection could be traced between them and the intestine.

In pigs, part of the pancreas lies upon the portal vein, and the authors, therefore, removed only the portion adjacent to the duodenum. In one animal which died a few weeks after the operation from accidental causes, they found in place of the portion of the pancreas removed, a cyst, the size of a hen's egg, which had no communication with the duodenum, and was filled with a fluid which, like pancreatic juice, was coagulated by alcohol.

In a second case operated upon in a similar manner, the weight of the animal increased in five and a half months, twenty-five kilogrammes. When the animal was killed, only a trace of the pancreatic duct could be discovered. The portion of the gland left had undergone atrophy, and contained no ducts. The atrophied portion was eight to ten centimeters distant from the duodenum, and one section gave evidence of having undergone sclerosis.

In five young dogs the pancreas was extirpated, leaving only that portion which lies upon the portal vein. All the animals remained well at the end of eight months. Three of the dogs were killed. In two of them the autopsy showed that the terminal extremity of the pancreatic duct remained as a blind pouch. The part of the gland left had become very much atrophied, and remained isolated from the duodenum. A glandular structure as large as a bean was found near the duodenum in both dogs; in one of them a duct connected this body with the bowel, while in the other no such connection could be traced. Taking it for granted that these small bodies were composed of pancreatic tissue, their weight being only about one-ninetieth part of the whole gland, the amount of secretion from them would not have been sufficient to emulsify the fats.

In the third dog no trace of the pancreas could be found, and yet the animal's digestion and health appeared to be normal. The fæces contained no undigested fat. From these and other experiments of the same kind, the authors came to the conclusion that the presence of the pancreatic juice is not essential in the process of

digestion or absorption of fat in herbivorous, carnivorous, or omnivorous animals, or in birds.

Schiff brought about complete suspension of the function of the pancreas in animals without removing any part of the organ, by injecting the ducts of the gland with melted paraffin, which, at the temperature of the body, became a solid mass, completely obstructing the outlets for the secretion. Animals treated in this manner showed no signs of derangement of digestion, and were able to assimilate fat as well as healthy animals.

The following experiments were made to ascertain the feasibility of complete extirpation of the pancreas, and the effects of such a procedure upon digestion and assimilation. In all of the experiments the entire organ was removed. The hæmorrhage was always profuse, and required numerous catgut ligatures for its arrest.

The larger vessels between the duodenum and pancreas were carefully isolated and removed with the gland, so that the intestine was deprived of its direct vascular supply over an area corresponding to the extent of the attachment of the pancreas.

Experiment 6. Brown dog, four and a half months old; weight thirty-two pounds. The entire pancreas was extirpated, part of the dissection was made with Paquelin's cautery. Temperature on second day 104° F., on fifth day 101.2° F. (subnormal). On the fourth day diarrhœa set in; stools contained undigested food and free fat, and on the seventh day blood. On the ninth day the animal died. During the first few days the appetite remained unimpaired, but when the diarrhœa supervened food was taken only sparingly.

At the autopsy it was ascertained that the animal had lost five pounds in weight. The abdominal cavity contained a considerable quantity of bloody serum, and the peritoneum presented evidences of recent diffuse peritonitis. The duodenum showed several dark spots on its convex surface, which might be taken for beginning gangrene. The pancreatic duct, traced from within the duodenum, was found closed at the point of section by a cicatrix upon the outer surface of the bowel. Whether in this case the diarrhœa resulted from the absence of the pancreatic juice or from the septic peritonitis, would be difficult to determine. The duodenum had been detached from its mesentery at least ten inches, and yet the gangrene, if any, after nine days was limited to a few circumscribed patches.

Experiment 7. Large black dog, four months old; weight forty-eight pounds. Experience had proved that the separation of the pancreas and its vessels from the duodenum could be done more safely, and with less risk of hæmorrhage, by tearing the tissues instead of using the scissors or knife, employing the cutting instruments only when it was thought imprudent to use

too much violence in separating strong connecting bands, which would not yield to gentle force. In this case twelve ligatures were required to arrest the hæmorrhage; in later experiments a much smaller number was found sufficient to arrest the bleeding, after I had learned to rely more freely on the tearing method in partial and complete extirpation of the pancreas. This dog never recovered fully from the operation and died on the fourth day, the temperature having remained subnormal during the whole of this time.

At the autopsy a perforation in the duodenum was found on the convex side about five inches below the pylorus; recent peritonitis, which was undoubtedly produced by extravasation consequent upon the perforation; gangrene of the bowel, circumscribed and limited to the seat of perforation, and a few other small spots on the convex snrface of the bowel. Pancreatic duct at point of section not closed. In this case death was directly attribntable to gangrene of the dnodenum, caused by the extensive detachment of its mesenteric vascular supply.

Experiment 8. Large adult cat. The operation occupied more than half an hour, and was attended by considerable hæmorrhage from the deep attachments of the gastrosplenic end. The bleeding was finally arrested by ligating a number of vessels in the region of the spleen. The animal never rallied from the operation and died five hours later with symptoms of hæmorrhage and shock combined. On opening the abdomen no blood was found in the peritoneal cavity, except a few flat coagula which covered the denuded surface of the bowel, which extended seven inches in length.

Experiment 9. Adult female cat. The extirpation was again attended by free hæmorrhage, and the animal died half an hour after the completion of the operation, with symptoms of hæmorrhage and shock.

Experiment 10. Adult black dog; weight thirty-three pounds. Animal remained comparatively well for two days, when peritonitis supervened, which proved fatal on the fourth day after the operation. Wound closed; peritoneal surfaces separated with some difficulty. The abdominal cavity contained a quart of purulent fluid. At the same time, diffuse general peritonitis had given rise to extensive adhesions between the different abdominal organs. The duodenum appeared quite vascular and showed no signs of gangrene.

Experiment 11. Medium-sized adult cat. After the extirpation of the entire pancreas, the duodenum was found on measurement to have been denuded of its mesenteric attachment to the extent of seven inches. The venous oozing proved free, and could not be completely arrested during the time which it was deemed prudent to keep the abdominal organs exposed to the atmospheric air. The animal never rallied from the operation and died two hours later. On opening the abdominal cavity, a considerable quantity of fluid venous blood was found. In this case death was caused by uncontrollable venous hæmorrhage.

REMARKS.—It will be seen that of six animals subjected to complete extirpation of the pancreas, in all cases death occurred in from a few hours to nine days after the operation. The cause of death

was either the primary effects of the traumatism, hæmorrhage, and shock, or from secondary pathological lesions traceable directly to the operation, as may be readily gleaned from the following table:

No.	Animal.	Time of death.	Cause of death.
1	Dog,	9 days,	Peritonitis.
2	"	4 "	Gangrene of duodenum.
3	Cat,	5 hours,	Hæmorrhage and shock.
4	"	30 minutes,	" " "
5	Dog,	4 days,	Purulent peritonitis.
6	Cat,	2 hours,	Hæmorrhage.

This table shows that the operation on cats proved more dangerous than on dogs, and of the three animals all died within five hours from the immediate effects of shock and hæmorrhage. The three dogs died of peritonitis within from four to nine days. In one case the peritonitis was due to perforation, in the remaining two it was produced through either the wound or the pancreatic duct, which was found open in one of the cases.

The complete extirpation of the pancreas necessitates such an extensive separation of the intestine from the mesentery, that this alone constitutes a great source of danger, as gangrene may take place. It is important to repeat that in the two specimens which showed evidences of gangrene this was observed on the convex surface of the bowel, and in neither case did it involve the entire diameter of the intestine. It requires no explanation to show that in cases of this kind the collateral circulation is established first on the concave side, where the vascular supply is nearest and the force of the circulation most vigorous.

In dogs and cats the pancreas is attached so intimately and extensively to the duodenum that complete extirpation is necessarily attended by profuse hæmorrhage, which often was found difficult, and in one instance impossible, to control. Ligation of some of the bleeding points was often found impossible, as any attempt at seizing the vessel necessarily grasped the muscular coat of the bowel, which it was thought to be dangerous to include in the ligature, as it might give rise to perforation. Steady pressure with a sponge wrung out of a hot, weak solution of corrosive sublimate was found to be the most reliable means in arresting troublesome oozing. None of these

experiments was sufficiently successful to study the effect of complete extirpation of the pancreas upon digestion and assimilation. In a number of the autopsies, however, the lacteals contained a milky fluid, showing that at least a portion of the fatty food had been emulsified by other secretions.

As a final conclusion, I do not hesitate to affirm that in dogs and cats complete extirpation of the pancreas is always followed by death, either from the primary effect of the operation, or the secondary consequences following it.

5. Partial Extirpation of the Pancreas.

Partial extirpation of the pancreas implies a less degree of traumatism, and consequently less danger of causing serious nutritive changes in adjacent organs than complete extirpation, and for these reasons it is less dangerous, in a strictly surgical sense. Physiologically, a partial extirpation of the organ may imply the same consequences as complete extirpation, as when the portion of gland removed embraces the common duct or both principal ducts from each portion of the gland.

Experiment 12. Adult cat; weight six and a half pounds. Pancreas drawn into the abdominal wound with the duodenum, and separated from the bowel to the extent of two inches, at a point corresponding to the middle portion of the gland. This section of the gland, which included the termination of the ducts, was excised with Paquelin's cautery; only one artery from the gastrosplenic end required ligature; ends of gland dropped into the abdominal cavity. The temperature remained subnormal, 101° F., until the animal died, two days after the operation. At the autopsy, gangrene and perforation of the duodenum were found at a point corresponding to the site of resection.

Experiment 13. Scotch terrier; weight twenty-five and a half pounds. Ligated pancreas at its middle, with catgut, and extirpated the gastrosplenic portion; eight ligatures were required to control the hæmorrhage and about four inches of the duodenum were denuded of its mesentery. Second day after the operation the temperature was 100.4° F., which became normal (103° F.) on third day. During the first week the animal gained one pound in weight, showing that digestion was not disturbed by the absence of the pancreatic juice during this time.

Three weeks after the operation the dog began to lose flesh; the emaciation was progressive until the animal died of marasmus seventy-six days after the operation. During this time the appetite was not impaired, and at no time had diarrhœa been observed. The organs of the chest were found in a normal condition. The abdominal wound was firmly united. A few adhesions

between the omentum and parietal peritoneum. No signs of peritonitis. The parenchyma of the duodenal portion of the gland had disappeared completely by absorption, only the connective tissue and the duct, somewhat dilated, remaining.

The idea that degeneration and absorption of the parenchymatous structure of the gland were caused by local anæmia could not be entertained for a moment, as the connective tissue frame of the gland was freely supplied with numerous and large vessels. The portion of the duodenum stripped of its mesentery was repaired by a vascular strip of connective tissue, which restored the continuity of the mesenteric circulation. The common pancreatic duct was found obliterated at its point of entrance into the bowel, where it had been divided during the operation.

Experiment 14. Adult cat; weight six pounds. Extirpation of gastrosplenic and half of the duodenal portion of the pancreas, with separation of duodenal mesentery to the same extent. The portion of the gland which remained was not ligated. The animal rallied from the immediate effects of the operation, but died eighteen hours later in convulsions. At the autopsy the mucous membrane of the duodenum in the portion of the bowel which had been deprived of its direct vascular supply, presented a cyanosed appearance, but no distinct signs of gangrene. Abdominal cavity contained no fluid of any kind; peritoneum normal in appearance. Slight hæmorrhage between peritoneum and transversalis fascia.

Experiment 15. Large adult dog; weight forty-eight pounds. Extirpation of two-thirds of the pancreas with the common duct, leaving only a portion of the remote end of the gastrosplenic portion. The hæmorrhage, which was profuse, was carefully arrested, and the pancreas ligated before section. The first two days the temperature was subnormal, 101°–102.2° F. On the third day it became normal and remained so. The animal remained in perfect health for four weeks, when he commenced to lose flesh. Appetite voracious. No diarrhœa, but stools contained undigested fat. Although the animal ate as much as four dogs of similar size, emaciation continued and had become extreme when the dog was killed, one hundred and twenty-six days after the operation.

At the autopsy the abdominal incision was found adherent to the mesentery. The duodenum which had been stripped of its mesentery was found free, without a mesenteric attachment, but freely supplied with blood by two large vessels running through a band of connective tissue adherent to the bowel on the concave denuded side. The vessels were in communication with the adjacent intact mesenteric vessels, and served to complete the interrupted mesenteric circulation. The gastrosplenic portion of the gland which was left behind was found completely atrophied; in its center the duct could be seen dilated to the size of a lead-pencil, and distended by a clear, transparent fluid. The dilated duct had no communication with the bowel. (Fig. 6.)

Remarks.—As in all of these experiments, the common ducts were removed with the excised portion of the pancreas, it left the

animal physiologically in the same condition as after complete extirpation of the organ, as no pancreatic juice could find its way into the intestine. In experiments 13 and 15 the dogs lived for a sufficient length of time to determine the influence of the pancreatic secretion upon digestion and assimilation. In both of these animals the general health and nutrition remained unimpaired for four weeks, when emaciation, with fatty stools, followed, which resulted in death from marasmus in one, after seventy-six days, and reduced the second dog to a skeleton in one hundred and twenty-six days.

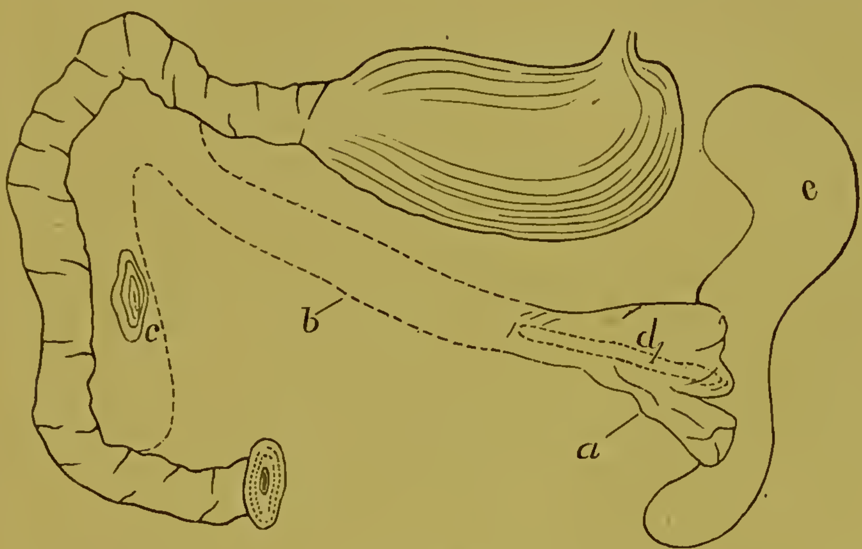

FIG. 6.

a. Remnant of pancreas.
b. Dotted lines, outlines of normal position of gland.
c. Connective tissue nodule.
d. Duct.
e. Spleen.

As from the beginning no pancreatic juice found its way into the intestine, it is difficult to account for the satisfactory condition of digestion, and the appearance of health of the animals for the first four weeks, followed by a progressive marasmus and increase of appetite. It is true that by the resection of the mesentery of the duodenum intestinal absorption was correspondingly diminished, but marasmus from this source ought to have manifested itself soon after the operation. It is now generally conceded that a healthy pancreas will absorb its own secretion in case there is any obstruction

to prevent the normal escape of the pancreatic juice, and it may be that pancreatic juice entering the circulation in this manner may have some as yet unexplained action on digestion. Should this be the case, we might assume that the pancreatic tissue left behind continued to secrete until the parenchyma was incapacitated by degenerative changes from performing this function.

All of the above experiments made on the pancreas tend to prove that any portion of the gland when it becomes detached from the bowel, invariably undergoes degenerative changes, and that its parenchymatous structure disappears by absorption within a few weeks. In these cases we may safely assume that the remaining portion of the gland had been rendered physiologically incompetent during the first four weeks, the time during which the animals remained in a healthy condition. In experiment 15 almost the entire duodenum had been suddenly deprived of its vascular supply, and yet no gangrene occurred. The collateral circulation was established by the development of two large vessels in a band of cicatricial tissue along the concave surface of the bowel, which restored the interrupted circulation between the mesenteric vessels on each side of the resected portion of the mesentery. It is also important to mention that in both dogs the lacteals appeared empty at the autopsy.

These experiments would then tend to prove that the pancreatic secretion is an important, if not essential, digestive fluid, and that in cases where no pancreatic juice can enter the intestine, or where the secretion is entirely suspended, digestion and assimilation become impaired in all cases where the supposed vicarious action of other organs is inadequate to perform the functions of the extirpated or degenerated pancreas.

6. Obliteration of the Pancreatic Duct by Elastic Constriction.

A favorite method of studying the effect of exclusion of the pancreatic juice from the digestive tract has been ligation of the pancreatic duct. Against the reliability of these experiments it may be urged that in many animals the pancreas possesses more than one duct, and in some of them accessory ducts may be present, which in all probability would be overlooked in the operation, and thus complete exclusion would not be secured. In some of the smaller animals even the common duct is often found only after a prolonged

and patient search, consequently any additional ducts or ductlets would be very likely to escape the attention of the operator. Rabbits have, as a rule, only one duct, which enters the intestine eight to ten inches below the pyloric orifice of the stomach; on this account the results obtained by experiments of ligating the duct have been most reliable when this animal was taken as a subject for experimentation.

Amozan and Vaillard[1] tied the pancreatic duct in rabbits, and studied subsequently the histological changes in the pancreas. Animals that survived the operation, and were killed after eight days, were considerably emaciated. On examining the pancreas it was found, as in the parotid gland after tying its duct, that an excessive amount of connective tissue had formed in and around the lobules, that the ducts were much dilated, and the epithelial lining partly thrown off; the epithelial cells had changed in position and form, and appeared atrophied.

A careful microscopical examination of the specimen showed that ligation of the duct of Wirsung produced a gradual transformation of the pancreas into connective tissue; the first effect was an enormous distention of the duct, which extended to the most remote portions of the gland. The epithelial cells became detached, and with a colloid material present, led to obstruction in the ducts. The gland cells, even as early as twenty-four hours after ligature, became translucent. After a few days the nuclei became swollen, and divided into two or three parts, which filled the interior of the cell. After seven to nine days, the place of the cells was occupied by free nuclei and round and spindle-shaped cells, which were transformed into connective tissue. In the neighborhood of some of the veins collections of colorless corpuscles could be seen. The gland, on the whole, had undergone cirrhotic atrophy.

According to Charcot and Gombault, the same cirrhotic change is produced in the liver by ligating the bile-ducts, while ligation of the ducts of the salivary glands and the ureters of the kidney produces only slight or no cirrhosis of those organs.

Bérard and Colin[2] ligated the pancreatic duct in dogs which had fasted for several days, and then fed them well for twenty-four hours. The animals either showed no appetite, or, after eating,

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[1] Pancréas du Lapin, Journ. de Méd. de Bordeaux, April 3, 1881.

[2] Gazette hebdomadaire, vi. 4, 1858.

ejected the food from the stomach. If the animals were killed, the lacteals were either only partially filled with a milky fluid, or, more generally, they were found empty.

The authors then tied the pancreatic duct in sixteen dogs which had fasted four or five days, and immediately injected into the duodenum a quantity of oil and lukewarm water. The animals were killed three or four days afterward, and the lacteals were found to contain a white opaque chyle both in the mesentery and walls of the intestine.

Cohnheim[1] claims that digestion is performed in a remarkably satisfactory manner, even in case the pancreatic juice is entirely absent, in the intestinal tract. He claims that the presence of fatty stools is the only symptom which can be positively brought in connection with a defective or total absence of pancreatic secretion. He asserts that in rabbits it is not difficult to ligate the pancreatic duct, and that in cases where this was done, with the exception of a loss of appetite for a few days, the animals suffered no bad consequences, and in a few days were as well as before the operation.

Langendorf ascertained by experiment that in pigeons a few days after obliteration of the ducts of the pancreas, the desire for food increased, but they emaciated progressively, because, as the author asserts, the carbohydrates were not digested. Cohnheim is of the opinion that in other animals the capacity of other organs to assume vicarious action is greater than in birds. Other digestive fluids perform the function of the pancreas. The transformation of starch into glucose is accomplished by the intestinal juice, and the emulsifying action of the pancreatic juice is assumed by the bile. The remnants of undigested peptones are removed by way of putrefaction induced by bacteria, which are always present in the intestinal tract.

That the pancreas continues to secrete after ligation of the common duct, has been demonstrated in Heidenhain's laboratory, where, thirty days after the duct had been ligated, normal pancreatic juice escaped through a cannula introduced into the duct. The quantity was only slightly less than from a normal gland, and the discrepancy was readily explained, as some of the gland structures must have been destroyed by the increased pressure in the duct

[1] Allgemeine Pathologie, Berlin, 1882.

from the accumulated fluid. As the organ continues to secrete, and the space for accumulation is limited, the only logical conclusion which can be arrived at is that the secretion is removed by the blood-vessels and lymphatics in the gland. It has been shown by Kühne that the introduction of pancreatic juice into the circulation does not act deleteriously, as he injected one of its most active constituents—trypsin—directly into a vein without any immediate or remote ill effect upon the animal. As he detected this substance in the urine, it is reasonable to assume that the ferments of the pancreatic juice which have not been neutralized by deoxidation into the more innocuous zymogen are eliminated with the renal excretions.

The following experiments were made, not so much to determine the effect of ligation of the pancreatic duct upon digestion, as with a distinct purpose of studying the effects, in the gland and its duct, which would follow sudden obstruction in the duct. Instead of resorting to direct ligation of the duct, the same object was accomplished with greater certainty and more ease by resorting to elastic constriction by using a rubber tube or band which was made to include the entire pancreas with or without its vessels. In every instance the elastic constriction produced complete division of the organ and its duct in a short time, and the ligature was usually found encysted either at the site of application or a little distance from it.

FIG. 7. Normal microscopic appearance of parenchyma cells from duodenal portion.

Experiment 16. Adult black dog; weight thirty pounds. Pancreas and duodenum were drawn into the abdominal incision, and a fine rubber drainage tube was passed between the duodenum and the pancreas at the junction of the middle with the proximal third, and firmly tied. The knot was kept from

unfastening by transfixion with a silk ligature. The vessels were included in the rubber ligature. The animal remained perfectly well after the operation and gained three and a half pounds in ten days. The dog was killed forty-nine days after the operation. On examination it was found that the abdominal

FIG. 8. Microscopic appearance of parenchyma cells in isolated splenic portion. × 500.

wound had healed completely; slight adhesions between the omentum and the lower portion of the cicatrix. The rubber ligature was found encysted at the junction of the middle with the proximal third (splenic end). The duodenal

FIG. 9. Sclerosis of splenic end. × 50.

a. Lobes showing fatty degeneration. *c.* Artery.
b. Connective tissue. *d.* Vein.

portion and the distal portion of the gastrosplenic end were unchanged, as the secretion could enter the intestine through the patent common duct. At the point where the ligature had been applied, the organ, with its duct, had been

completely divided, the point of section being indicated by a contraction due to cicatrization. The duct in the isolated splenic portion was slightly dilated; parenchymatous tissue in a state of degeneration; well-marked sclerosis. (Figs. 7, 8, 9.)

Experiment 16a. White and yellow coach dog, four and a half months old; weight thirty-two pounds. In this case the rubber ligature was applied about the middle of the gland, including the artery, but not the vein. The animal remained in excellent health, and was killed ninety-eight days after the operation. At the autopsy the ligature was found encysted in a firm capsule about the middle of the gland. It had completely divided the pancreas and the duct of the splenic portion on the proximal side of the common duct. The duct in the isolated portion was considerably dilated throughout, and com-

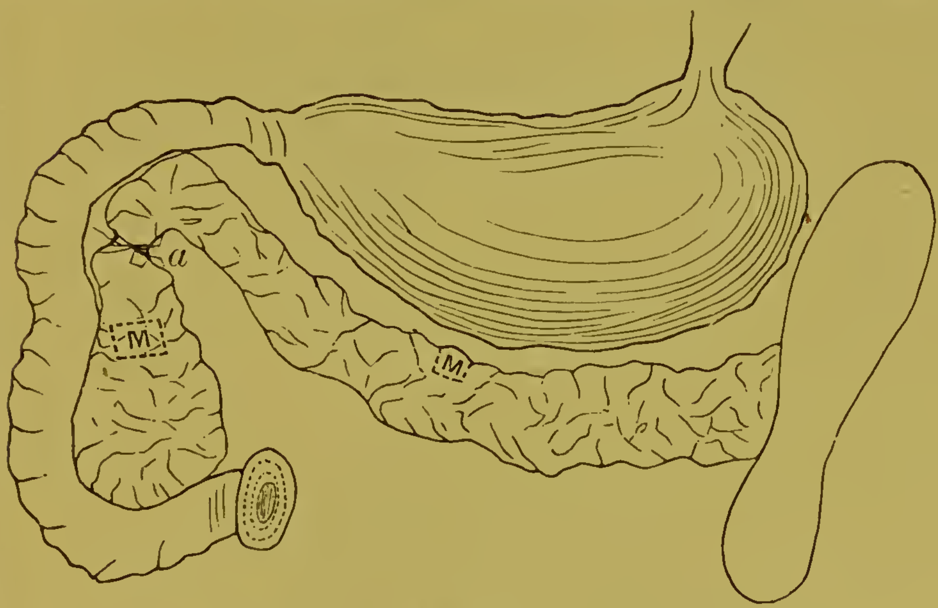

FIG. 10.

M. Point from which microscopical sections showing normal cells were taken.

M'. Point from which microscopical sections showing degenerated cells were taken.

a. Ligature.

pletely obliterated at the point of ligation. This portion of the gland had undergone parenchymatous degeneration and sclerosis, as the tissue was quite firm, and grated on being cut with the knife. The portion of the gland remaining in communication with the intestine through the common duct presented a normal appearance.

Experiment 17. Adult black dog; weight twenty pounds. Ligation of pancreas on the proximal side of the common duct, excluding the artery. The dog remained perfectly well after the operation, gained considerable flesh,

and was killed in four weeks. The rubber ligature was encysted between the duodenum and pancreas. Complete division of pancreas and duct on the splenic side of the common duct. Slight dilatation of the duct in isolated portion, with the same tissue changes as in the preceding case.

FIG. 11. Section taken from M, splenic portion, showing normal parenchyma. × 500.

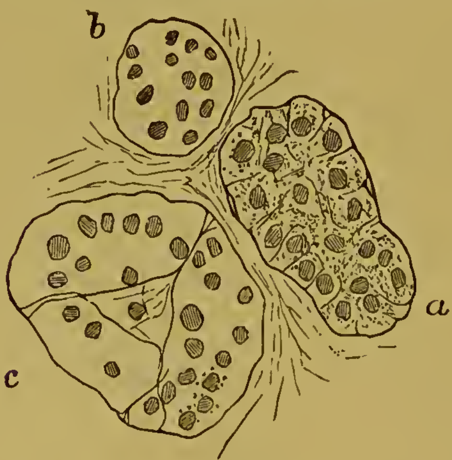

FIG. 12. Incomplete fatty degeneration, from duodenal portion of gland. × 500.

Experiment 18. Adult black cat; weight five and a half pounds. The pancreas was detached from the duodenum to the extent of three-quarters of an inch, and the rubber ligature applied so as to exclude the artery. On the second day the temperature rose to 106° F., but the general condition of the animal was undisturbed. The fever soon subsided, and digestion and nutrition were at no time impaired. The cat was killed thirty-eight days after opera-

tion. The ligature was found encysted between the pancreas and duodenum on the distal side of the common duct. Complete division of the pancreas and obliteration of the duct by a linear cicatrix. The detached mesentery was united with the bowel. The detached duodenal portion of gland had almost disappeared by absorption, only connective tissue and vessels being left to indicate the contour of the gland. (Figs. 10, 11, 12, 13.)

FIG. 13. Complete fatty degeneration, from duodenal portion of gland. *a*. Artery.

Experiment 19. Adult white cat; weight six and a half pounds. Detached pancreas and vessels from duodenum to the extent of an inch and a half, and applied a rubber ligature about the middle of the gland, including the vessels. Next day the temperature was 105° F.; later, normal. No disturbance of digestion or nutrition. The cat was killed eighty-five days after operation. The rubber ligature was encysted between duodenum and pancreas on distal side of the common duct. Complete section of pancreas and obliteration of duct. The duodenal portion had almost completely disappeared by absorption; the connective tissue of the gland, the dilated ducts, and the abundant vascular supply, served to indicate the outlines of the atrophied portion. Mesentery of the duodenum was perfect. (Fig. 14.)

Experiment 20. Young black cat; weight two pounds. Isolated pancreas to the extent of two inches from intestine, and included the detached portion between two silk ligatures, firmly tied. Temperature was high on second and sixth days. Animal died on sixth day. Abdominal wound was firmly united. On opening the abdominal cavity no effusion was found. No general peritonitis. Abscess between duodenum and liver; ligated portion detached, gangrenous; ligatures not encysted. Abscess in communication with pancreas. Acute atrophy of the entire pancreas. No gangrene of duodenum. In this case the suppurative process started from the portion of pancreas which had been included between the ligatures. We shall find that when infection does not take place, even isolated dead pancreatic tissue is amenable to absorption.

Experiment 21. Old cat; weight four pounds. Detached gastrosplenic portion of the pancreas to the extent of an inch and a half from duodenum, and applied two rubber ligatures about half an inch apart, including the

vessels. On the following day the cat was quite ill, without any rise in temperature. For several days vomiting was the most prominent symptom. The animal died on the sixth day. Abdominal wound united; no peritonitis; no effusion. Pancreas adherent to transverse colon; on separating the adhesion a small cyst containing about three drachms of a clear, transparent fluid was ruptured. As this cyst corresponded to the place where the ligatures had been applied, it was undoubtedly a collection of pancreatic juice which had escaped from the divided duct, and around which a connective tissue wall had formed. The ligatures had cut through the organ and duct. The ends of the gland had retracted. Duodenum healthy. Mesenteric detachment not repaired. No suppuration anywhere.

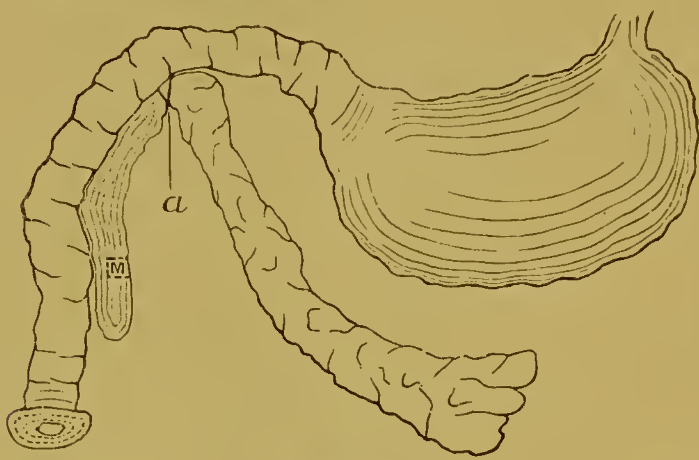

FIG. 14.

a. Ligature.

M. Portion taken for microscopical examination which showed complete absence of parenchyma cells.

Experiment 22. Adult dog; weight thirty-nine pounds. Detached the pancreas, about its middle, from duodenum, to the extent of two inches, and applied two rubber ligatures, about one inch apart, including the vessels. On the following day the dog appeared quite sick. Increase of temperature after sixth day; no appetite, and rapid emaciation. On the ninth day, diarrhœa, which became later dysenteric in character. Died on the nineteenth day, having lost during this time six and a half pounds in weight. Abdominal wound completely united. No general peritonitis. Pancreas and duodenum adherent to liver. Portion of pancreas between ligatures gangrenous—contained in an abscess cavity. Ligatures detached and loose in abscess cavity.

Experiment 23. Adult black dog; weight twenty pounds. Inclusion of two inches of the pancreas and its vessels, after separation from duodenum, between two silk ligatures about the center of the gland. The dog was very sick on second day, and thermometer showed an increase of temperature to 104.4° F., which continued with slight variations until the animal died on the

sixth day. Wound completely united. Diffuse purulent peritonitis, and extensive adhesions. Ligated portion gangrenous and loose, with ligatures in abscess cavity between duodenum and pancreas.

Experiment 24. Adult gray cat; weight five and three quarters pounds. Isolated pancreas and vessels from duodenum to the extent of an inch and a half, and included this portion between two ligatures. Animal remained well for four days, when symptoms of peritonitis appeared. Died on tenth day. Wound nicely united. No peritoneal effusion. Localized peritonitis at site of operation. Ligatures and ligated section of pancreas loose in abscess between the duodenum and pancreas. Pancreatic veins thrombosed. Duct of splenic portion in direct communication with the abscess cavity.

Experiment 25. Adult cat; weight six pounds. Pancreas with its vessels detached from duodenum to the extent of two inches, and this portion included between two ligatures. On fifth day temperature 106° F., gradual decrease subsequently to normal. For a number of days during the febrile attack,

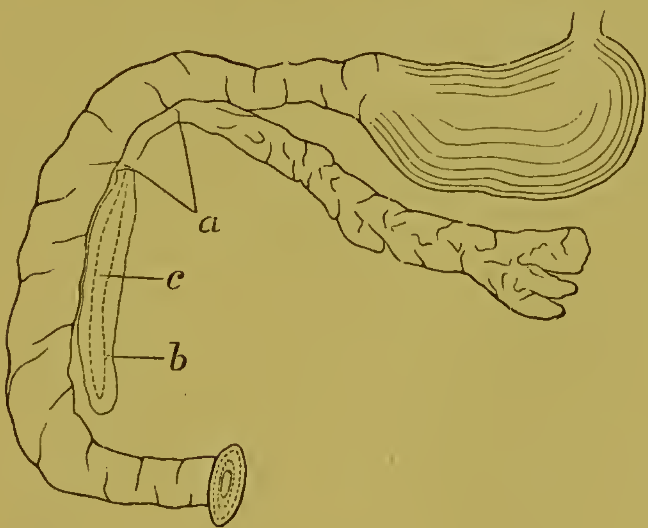

Fig. 15.

a. Ligatures.
b. Duodenal portion atrophied and undergoing fatty degeneration.
c. Dilated duct.

complete loss of appetite. After this, appetite and nutrition were good. Killed twenty-eight days after operation. Portion of gland between ligatures completely disappeared by absorption. Ligatures in close proximity and encysted in firm capsule. Duodenal end atrophied, in which the dilated duct was distinctly visible. Splenic end somewhat atrophied. (Fig. 15.)

Experiment 26. Large Newfoundland dog; weight fifty-five pounds. Rubber ligatures made to include one inch of the pancreas about its middle, with exclusion of its vessels. Slight fever on third day, subsequently no symptoms indicating disturbance of digestion or disease. Animal killed

thirty-one days after operation. Intervening portion of pancreas disappeared by absorption. Ligatures encysted. Loss of substance replaced by bridge of connective tissue. Duodenal end atrophic, with dilated duct. Gastrosplenic portion normal in appearance, and in direct communication with the intestine through the common pancreatic duct.

Remarks.—Only two of the animals recovered after isolation and double ligation of the pancreas, a fact which shows the great danger of leaving pancreatic tissue not supplied with blood in the abdominal cavity. We can only assume that the danger of infection is increased by leaving an exceedingly favorable culture substance for infective germs in the abdomen. If the operation is perfectly aseptic, the dead pancreatic tissue remains aseptic, and is removed in an exceedingly short time by absorption.

Fig. 16. Posterior view.

a. Common duct.
b. Ligature.
c. Duodenal portion, atrophy and fatty degeneration marked, duct dilated.
d. Liver, pancreas adherent to.

Experiment 27. Large adult cat. Applied a single rubber ligature on distal side of the common pancreatic duct, excluding the artery and vein. No disturbance of digestion or nutrition, and temperature normal throughout. Animal, when killed twenty-eight days after operation, had grown fat. Only a few slight adhesions at site of ligation. Pancreas and duct were completely divided by the ligature, the ends kept in contact by a linear cicatrix. Liga-

ture was encysted between the duodenum and under surface of the liver. The gastrosplenic portion of the pancreas was normal in appearance, and connected with the common duct. The duodenal portion was atrophied; the duct slightly dilated. (Fig. 16.)

Experiment 28. Large Newfoundland dog. Ligation of the pancreas and its vessels with a rubber ligature on the proximal side of the common duct. No fever, no disturbance of digestion or nutrition. Animal was killed ninety-one days after operation. On opening the abdominal cavity, the entire pancreas presented a normal appearance in size, shape and consistence. Where the ligature was applied a narrow constriction was visible, which represented

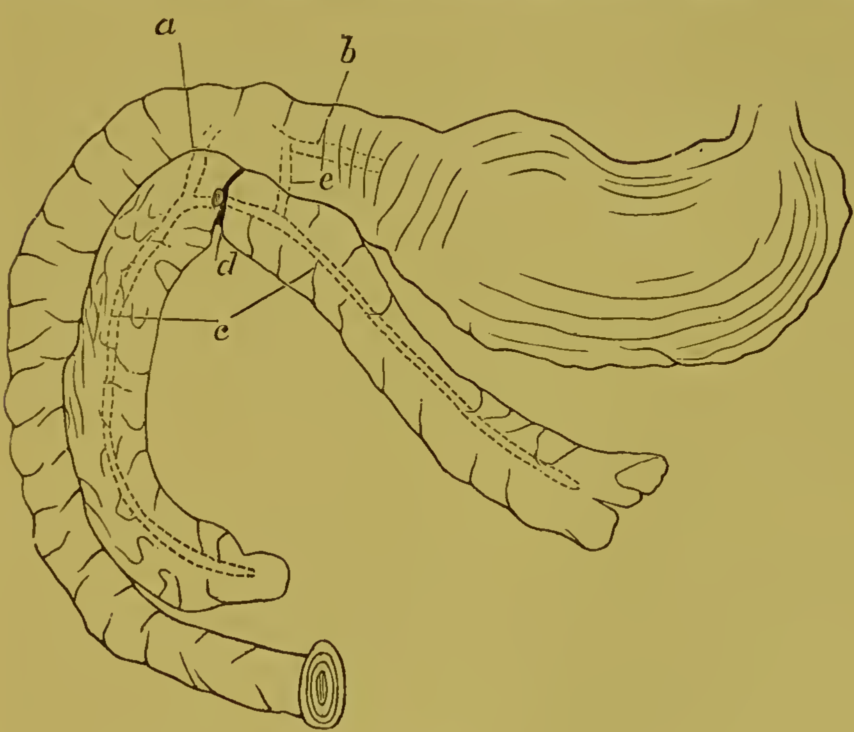

FIG. 17.

a. Duct of Wirsung.
b. Ductus choledochus.
c. Main pancreatic ducts.
d. Ligature.
e. Accessory duct.

the point of section made by the ligature. Ligature was encysted in the cicatrix. On tracing the pancreatic duct from the interior of the intestine, a probe could be passed along the duct of the duodenal portion. On following the duct of the splenic portion, the probe was arrested at the cicatrix, about a quarter of an inch from the wall of the intestine. The duct at this point was completely obliterated.

As in all of the previous experiments the detached portion of the gland had invariably become the seat of degenerative changes and atrophy, I was at a loss to account for the normal appearance of the gastrosplenic portion of the gland in this instance. After a prolonged and careful search a minute opening was detected in the fold of the mucous membrane surrounding the outlet of the bile-duct, and by careful manipulation a delicate probe was passed along a canal which passed obliquely through the wall of the bowel, entered the pancreas on the splenic side of the ligature, and terminated in the large duct of the gastrosplenic portion. (Fig. 17.)

The explanation for the absence of atrophic changes had been found. An accessory duct had furnished an outlet for the secretion in the gastrosplenic portion, and had maintained the physiological connection between this portion of the gland and the duodenum after obliteration of the common duct of the gastrosplenic portion. It was the only instance where such a structure was detected, and the only specimen in which the normal structure of the detached portion of the gland was preserved after obliteration of the principal duct.

Remarks.—These experiments illustrate the feasibility of ligation of either portion of the pancreas near the common duct as a surgical procedure, and the regularity with which the pancreatic tissue is removed by degeneration and absorption in the detached portion of the gland. By physiological detachment, I mean a permanent interruption to the escape of secretion, by section or obliteration of the duct.

After ligation of the duct or gland, secretion continues, and as the space for accumulation of the fluid is limited, a certain degree of pressure within the duct is established, as is evident from the uniformity with which the ducts throughout that portion of the gland were found dilated. In no instance, however, was anything observed which resembled a cyst. The dilatation was not limited to any particular portion of the duct, it always presented itself as a uniform ectasia of the entire duct. We can only explain the moderate dilatation by assuming that, as soon as a certain degree of pressure is reached, the pancreatic juice is removed by the vessels and lymphatics of the pancreas, by absorption, and that a greater accumulation of fluid and distention of the duct could only occur when this function has become diminished or suspended by organic changes in the structures which are concerned in the removal of the secretion. The atrophic changes in the parenchyma of the detached portion of the gland have been ascribed to the pressure within the ducts upon the parenchyma cells—a sort of pressure atrophy.

This supposition lacks proof, inasmuch as the pressure at any

time could not have been considerable, and as the same atrophic changes have been observed in cases where no pressure could have existed, as in cases of external and internal pancreatic fistula, where the duct remains open until secretion ceases. The atrophy can also not be due to deficiency of blood supply, as it occurred regularly and as rapidly in cases where the blood supply remained unimpaired; and in many of the specimens, illustrating complete atrophy, the abundant vascular supply was distinctly observed and noted. I am unable to furnish a satisfactory explanation of the cause of this form of atrophy. All that I can say is, that in every instance in which complete physiological detachment had been produced by ligation, resection, crushing, or any other means, this result followed without exception.

Practically this observation is of great importance, because it demonstrates that in operations upon the pancreas it is not essential or necessary to remove peripheral portions of the gland, for fear that if any of the parenchymatous structure should remain a retention cyst would follow. In partial resections for injury or disease it would be advisable to ligate the peripheral portion, and permit it to remain, as it would lessen the danger by the infliction of less traumatism, and as we can confidently expect that it will be removed in a short time by absorption.

These experiments settle definitely an important pathological question. It has been claimed by all writers that cysts of the pancreas are produced by obstruction of the common duct. In most of the specimens which have been examined, it is distinctly stated that the obstruction was not complete, as, for instance, in cases of impaction of pancreatic calculi when found in connection with cysts. In all of these experiments obstruction of the duct was sudden and complete by the elastic constriction, and subsequently permanent by the formation of a cicatrix between the divided ends of the duct.

In none of the specimens, where life was sufficiently prolonged, did the process of obliteration fail to take place, and yet in none of them was even an attempt at the formation of a cyst observed.

The experiments with the double ligature teach the importance of removing such portions of the pancreas as are not supplied with blood-vessels, rather than trusting to the doubtful expedient of leaving them to be removed by absorption; as dead pancreatic tissue is

an exceedingly putrescible substance, and furnishes the most favorable conditions for the growth and increase of septic germs.

7. External Pancreatic Fistula.

The formation of a permanent pancreatic fistula has always constituted one of the most difficult tasks in experimental physiology. Bernard,[1] after many fruitless attempts, declared that it was impossible to establish a permanent pancreatic fistula, for the reason that the cannula invariably fell out after a few days, after which the duct again conveyed its contents into the duodenum. He found, also, that the pancreatic juice which flowed from the fistula remained normal for only twelve or sixteen hours, after which time it became thinner, and did not coagulate on the application of heat. Neither did it possess any longer the property of decomposing fat into glycerine and fatty acids. This change in the pancreatic juice always appeared as soon as inflammation was noticed about the seat of operation. In horses and cattle this condition appeared so early, that it was found impossible to obtain pure pancreatic juice from a fistula.

The intermittent action of the pancreas is well illustrated in animals when a fistula has been established, active secretion taking place only during digestion. Bernard ascertained that in medium-sized dogs not more than five or six grammes of juice could be obtained in an hour. Ether injected into the stomach increased the secretion, while vomiting suspended the flow of fluid, but not its secretion, since just after the act it was poured out in so much greater quantities. Pressure on the abdomen and the respiratory movement of the chest accelerated the flow from the fistula.

The following experiments were made for the distinct purpose of studying the functional activity of a detached portion of the pancreas, consequently a different method of operating had to be devised. Having satisfied myself that physiological detachment of a portion of the pancreas by section, resection, or ligation always results in degeneration of the parenchyma, and atrophy of the detached portion, I determined to study this subject more thoroughly by interrupting all anatomical continuity between the detached and the principal portion of the gland.

[1] Leçons de physiol. expér. appliquée à la médecine, t. ii., Paris, 1855.

An external pancreatic fistula was established by bringing the pancreas with the duodenum into the wound, ligating the pancreas usually below the common duct, dividing the gland and its vessels completely on the distal side of the ligature, arresting carefully the hæmorrhage from the cut surface without interfering with the principal duct, detaching the distal, or duodenal portion sufficiently from the bowel, so as to bring the cut surface a little above the level of the outer surface of the wound, where it was fixed with four catgut sutures to the margins of the wound. The remaining portion of the wound was closed in the usual manner. This method secured a permanent pancreatic fistula, the outflow from which would indicate the amount of secretion from the detached portion of the gland.

Experiment 29. Young dog; weight thirty pounds. Ligation of pancreas at junction of middle with distal portion, section of gland immediately below ligature, separation of detached portion from duodenum to the extent of two inches, implantation of free end into the lower angle of the abdominal incision with four catgut sutures. During the second day, slight rise in temperature. During the first day the dog refused to eat, and no pancreatic juice was seen to escape from the cut surface of the gland. The second day the secretion was copious, resembling normal pancreatic juice. The discharge was intermittent, most copious a few hours after eating, and entirely absent when the animal fasted. At the end of the first week, the secretion became less in quantity, and gradually continued to decrease until it ceased entirely on the twenty-first day. The portion of the pancreas included in the wound became smaller from day to day, and appeared to have disappeared almost entirely when the secretion ceased, leaving at this place an irregular depressed cicatrix, with no tendency to hernial protrusion. The animal remained in perfect health and was killed seventy days after operation.

At the autopsy, the cut end of the atrophic duodenal portion of the pancreas was found adherent to, and incorporated in the firm cicatrix of the abdominal wound. The parenchyma in the detached portion of the gland had disappeared completely; in the center of this portion the principal duct could be seen dilated to the size of a lead-pencil, and containing a clear, transparent fluid. The duct could be traced to the peripheral extremity of the gland in one direction, and into the cicatrix of the abdominal wound in the other. The atrophic portion of the gland was freely supplied with blood-vessels. The duct was widest near the cicatrix, and gradually tapered toward the end of the gland. The cut proximal end had become adherent to the duodenum. A probe could be passed from the duodenal end of the common pancreatic duct along the entire distance of the splenic portion; the point of section had evidently been made on the peripheral side of the common duct, through the duodenal portion of the gland. (Fig. 18.)

Experiment 30. Adult cat; weight five pounds. In this case the gland was divided near the middle. The duodenal portion was detached from the

intestine to the extent of two inches, and sewed into the lower angle of the incision. Second day, temperature, 108.5° F. The animal took but little food, and only a very small amount of secretion was observed to escape from the duct on the cut surface of the gland. The cat died on the third day, after the temperature had shown an increase to 106° F. At the autopsy it was shown that death had resulted from purulent peritonitis, and croupous pneumonia of right lung. No gangrene of duodenum or pancreas.

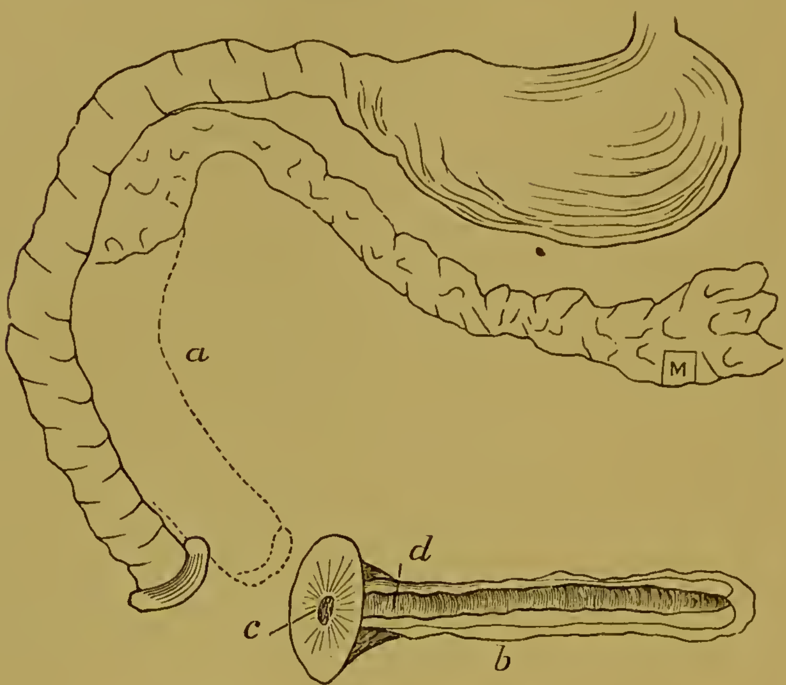

FIG. 18.

a. Point of division of gland.
b. Portion of gland planted into wound, showing complete atrophy.
c. External cicatrix.
d. Dilated duct.
M. Portion taken for microscopical sections, showing normal structure of gland.

Experiment 31. Adult cat; weight five and three-fourths pounds. Operation same as before. The animal was quite ill for three days; at the end of this time the temperature was 104.8° F.; took but little nourishment. From this time improvement took place, and finally complete recovery. Escape of pancreatic juice was first observed on second day; it gradually increased for three days, when it began to diminish and ceased completely on the seventeenth day, when the wound closed completely, showing no tendency to ventral hernia. Unfortunately the animal was lost on the forty-eighth day.

Experiment 32. Black shepherd dog; weight forty-three and a half pounds. Ligation of pancreas about its middle, double ligation of pancreatico-duodenal artery, division of gland, application of four ligatures to arrest hæmorrhage from the distal portion of the gland, detachment of duodenal end to the extent of two inches from intestine, and fixation of free end into the lower angle of the incision by four catgut sutures. No untoward

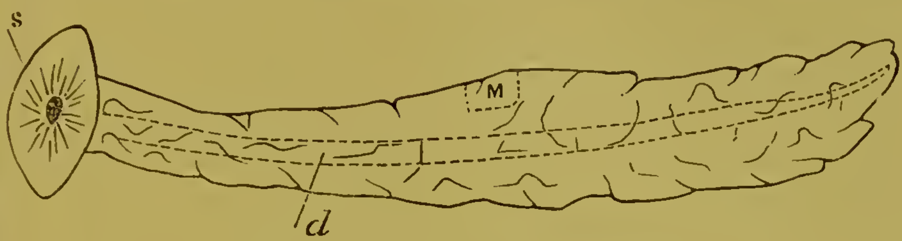

FIG 19. External pancreatic fistula.

s. Portion of skin with external cicatrix in center.
d. Dilated duct.
M. Portion taken for microscopical examination, showing advanced fatty degeneration of parenchyma, and sclerosis throughout entire transplanted portion of gland.

FIG. 20. External pancreatic fistula, from duodenal portion of gland.

Some of the acini completely empty, others show groups of cells in advanced stage of fatty degeneration.

symptoms after operation. Free escape of pancreatic juice at the end of the second day, which continued quite profuse for ten days during digestion, when it began to diminish, and ceased entirely on the twenty-fifth day after the operation. During the first six days the animal lost four pounds in weight, after this time digestion and nutrition were perfect. The dog was killed

forty-six days after operation. Post-mortem appearance was almost identical with that in experiment 29, except that the duodenum was found adherent to the under surface of the liver. The vascularity of the atrophic duodenal end was particularly well marked. (Figs. 19, 20.)

REMARKS.—These experiments have demonstrated conclusively that when a portion of the pancreas is detached by complete section, secretion continues until, by degeneration and absorption, the parenchyma of the gland has disappeared. The degeneration evidently commences at the end of eight to twelve days, and progresses rapidly and continuously until the end of twenty to twenty-seven days, when all of the secreting structures have lost their physiological function, as indicated by a permanent cessation of the flow of pancreatic juice. The existence of distention of the principal duct in these cases can only be explained by assuming that it occurs after closure of the fistula has taken place by an accumulation of secretion from the lining of the duct, or that the dilatation is caused by traction upon the outer surface of the duct by the connective tissue framework of the gland, or the contraction incident to interstitial connective tissue proliferation.

That the atrophy in the part of the organ which had been detached from its connections with the intestine was not due to a traumatic interstitial pancreatitis is proved by the normal appearance and structure of the remaining portion of the gland which had retained its anatomical and physiological relations to the intestine. I am, therefore, again supported in the assertion that physiological detachment of any portion of the pancreas is invariably followed by degeneration and complete atrophy, consequently also by complete cessation of functional activity.

8. Internal Pancreatic Fistula.

It is a well-known fact that when pancreatic juice is brought in contact with the skin it produces irritation, an effect which has been attributed to its digestive qualities. In all the animals where an external pancreatic fistula was established, the skin appeared sore and macerated as far as it had been kept moist with the pancreatic juice.

Clinical observation has shown that in nearly all cases where a cyst of the pancreas was treated by the formation of a pancreatic fistula, the skin around the fistula remained in an eczematous condi-

tion so long as the fistula continued to discharge fluid. Taking these facts into consideration, we should naturally anticipate that when pancreatic juice is brought in contact with the peritoneum it will produce a destructive effect upon it by its digestive properties, or that it may be even followed by diffuse peritonitis.

In opposition to this reasoning, Bernard informs us that none of his animals died when he had made a pancreatic fistula, and as in these cases extravasation of pancreatic juice into the peritoneal cavity was almost inevitable, it would appear that its effects here are not so disastrous as when it acts upon the skin.

Concerning this point, Heidenhain remarks: "The animals do not suffer from this circumstance, as the duct is regenerated in spite of the wounded surface being bathed in the secretion. Nevertheless, it is difficult to explain this. Why do not the wounded and suppurating tissues undergo digestion by the pancreatic juice? The efficacy of the albumen ferment is destroyed in some way, I presume, probably by being converted into zymogen, the living tissues having the effect on the juice as Podolinski observed, by treating the pancreatic juice with powdered zinc or yeast ferment."

As pancreatic juice, when brought in contact with the atmospheric air, may undergo rapid changes, and thus be rendered abnormal, experiments made with it by injecting it into the peritoneal cavity would not represent the action of normal pancreatic juice upon the peritoneum, hence the results obtained would not represent the effects of normal secretion.

To determine the effect of normal pancreatic juice on the peritoneum, I resorted to the formation of an internal pancreatic fistula, so as to bring the peritoneum in contact with the normal pancreatic secretion as it escaped from the cut surface of the gland. My experiments with external pancreatic fistula had taught me that the isolated portion of the gland continued to secrete for seventeen to twenty-six days; hence, I was convinced that if I could establish the same conditions within the peritoneal cavity, I would secure an intermittent flow of normal pancreatic juice into the peritoneal cavity for the same length of time. The operation was performed in precisely the same manner as for external fistula, except that the cut end of the duodenal portion was detached from the duodenum, turned downward, and dropped into the peritoneal cavity.

Experiment 33. Young dog; weight thirty-one and a half pounds. Divided the pancreas near middle, detached duodenal end from bowel to the extent of three inches, turned it downward, and closed the abdominal wound completely. Second day, temperature 106° F.; slight tympanites. Dog appeared quite ill for a number of days, and temperature remained above normal for a week, although the animal remained in good condition until killed, seventy-six days after the operation. The autopsy showed evidences of a former local peritonitis at the site of operation; the duodenal or detached end of pancreas was completely atrophied, its ducts dilated, closed, and adherent to duodenum. Splenic portion normal in site and appearance; cut end adherent to duodenum; common duct pervious.

Experiment 34. Adult dog; weight twenty-one pounds. Detached pancreas from its middle toward distal side to the extent of five inches. Divided the pancreas with Paquelin's cautery, between two compression forceps; used no ligatures. Turned end of lower portion downward, and closed the abdominal incision. Animal died on the third day, with symptoms of peritonitis. No rise in temperature. Post-mortem examination showed evidences of diffuse purulent peritonitis; no hæmorrhage, no sign of gangrene of duodenum.

Experiment 35. Adult dog; weight thirty-seven pounds. Ligated pancreas on distal side of common duct. Divided the gland transversely just below ligature, tied vessels with catgut, detached duodenal portion from intestine to the extent of three inches, turned the free end downward, and closed the abdominal incision. Temperature remained normal, but the animal was reported sick for five days, when recovery set in, and the dog remained in good health as long as he was under observation—thirty-two days, when he ran away.

Experiment 36. Adult cat; weight five and a quarter pounds. Applied ligature below common pancreatic duct, and divided the gland on distal side of ligature, detached duodenal portion from intestine to the extent of two inches, turned the free end downward, and closed the abdominal wound. The animal remained well after the operation, and was in good condition when killed eighty-three days after the operation. Great omentum was adherent to lower border of liver; mesentery adherent to duodenum; duodenal portion of gland completely atrophied; cut extremity of splenic portion adherent to duodenum by a firm cicatrix just below the entrance of the common duct into the intestine. This portion of the gland was normal in size and appearance. Atrophied portion was abundantly supplied with blood-vessels.

Experiment 37. Adult cat; weight five and a half pounds. Pancreas was ligated just below the common duct, transverse section of the pancreas below ligature, detached the peripheral portion to the extent of an inch and a half, turned the free end downward, and closed the abdominal incision. Death on third day. No hæmorrhage into the abdominal cavity; diffuse purulent peritonitis; adhesions between the duodenum, liver, and greater omentum.

Experiment 38. Young cat, same operation as in previous experiment. No serious symptoms were observed after the operation. About two weeks later progressive emaciation, until the animal died forty-two days after operation. At the post-mortem, an extensive abscess was found underneath the skin over the sacrum. Some evidences of previous peritonitis, but no effusion or suppuration. Duodenal or detached portion quite vascular, but in a condition of advanced atrophy. Splenic portion was normal in size and appearance, but cut end was firmly adherent to the duodenum below the entrance of the common duct.

Experiment 39. Young cat. Operation the same, followed by no serious symptoms and no rise in temperature. Animal was killed seventy days after the operation. At the autopsy the lower border of the liver was found adherent to the cicatrix of the abdominal wound. Duodenal portion was completely atrophied. At the point where the duodenum was denuded of its mesentery, the bowel had become acutely flexed by cicatricial contraction which approximated the raw surfaces. The same cicatrix connected the atrophied and intact portion of the pancreas.

Experiment 40. Adult cat. Pancreas detached from duodenum to the extent of an inch and a half, otherwise operation same as in preceding cases. Rise in temperature on fourth and seventh day, otherwise the animal was in good condition. Killed forty-two days after the operation. Animal was well nourished. Great omentum adherent to cicatrix of wound. At the point where the gland was detached from the duodenum, the bowel doubled upon itself acutely, the raw mesenteric surfaces being in direct contact. The connective tissue remnant of the duodenal portion was incorporated in this cicatrix but could be readily identified. Cut surface of splenic end was firmly adherent to the duodenum below the entrance of the common duct; presented normal appearance in size, structure and shape.

Experiment 41. Young cat. Operation the same as in preceding case. Temperature on fifth day, 105.5° F. Animal was killed on seventh day: wound not completely healed; abscess on concave side of the duodenum; no peritoneal effusion or signs of general peritonitis.

Experiment 42. Adult dog; weight thirteen pounds. Operation same as before, mesenteric denudation of duodenum two inches. From second to eighth day slight rise in temperature. Animal in excellent condition when killed thirty-five days after operation. Small ventral hernia. A number of adhesions at site of operation. Mesenteric circulation at point of detachment restored by a plexus of new vessels, contained in a narrow band of cicatricial tissue. Duodenal portion almost completely absorbed, only a few scattered imperfect lobules visible. Splenic end normal and in communication with duodenum through common duct.

Experiment 43. Adult dog; weight fifteen pounds. Operation same as in preceding experiment. No disturbance of digestion or nutrition, and no rise in temperature. Animal was in good condition when killed thirty-five days after operation. Duodenal portion indurated and contracted into a

hard string which contained a dilated duct. Liver adherent to diaphragm. Duodenum without a proper mesentery over a space of several inches, vascular supply furnished by new vessels passing along the surface of the bowel on the concave side. Examination showed that ligature had been applied on splenic side of duct, and that the section had probably been made near or through the common duct, as the splenic portion was also in a state of advanced atrophy and not in communication with the bowel. The duodenal portion was in a state of extreme atrophy, much shortened, and firmly adherent to the bowel. Just below point of operation, a small encapsulated abscess was found on the convex side of the bowel. In this case no pancreatic juice could gain entrance into the bowel, and yet digestion and nutrition appeared to be unimpaired.

Remarks.—As in cases of external pancreatic fistula the secretions often amounted to more than four ounces a day, we have every reason to believe that the same quantity was secreted and discharged into the peritoneal cavity in the cases in which an internal pancreatic fistula was established. The effect, if any, of the pancreatic juice upon the peritoneum can be seen best by an examination of the following table:

Experiment No.	Animal.	Time of death.	Cause of death.
33	Dog,	76 days,	Purulent peritonitis.
34	"	3 "	Killed.
35	"	Living,	Ran away 32d. day.
36	Cat,	83 days,	Killed.
37	"	3 "	Purulent peritonitis.
38	"	42 "	Abscess in sacral region.
39	"	70 "	Killed.
40	"	42 "	"
41	"	7 "	"
42	Dog,	35 "	"
43	"	35 "	"

In only two of the eleven experiments was death caused by purulent peritonitis. In one a circumscribed abscess was found in the concavity of the duodenum, and in one animal a small abscess, with thick walls, was found on the convex surface of the duodenum, which did not give rise to any symptoms during life. One of the cats died from the consequences of a large abscess over the sacrum, forty-two days after the operation. The post-mortem appearances in the abdomen pointed to only a very circumscribed peritonitis at the seat of operation. As the mortality after the formation of an

internal pancreatic fistula did not exceed the death-rate of any other form of operation upon the pancreas, we are justified in the assertion that normal pancreatic juice when brought in contact with the peritoneum does not produce peritonitis.

Another question which presents itself is this: What becomes of the pancreatic juice in the peritoneal cavity? No mention is made in the autopsy records of these cases of the presence of any kind of effusion in the peritoneal cavity, except in the two cases where death resulted from purulent peritonitis, when the abdomen contained a considerable quantity of a sero-purulent fluid thrown out by the inflamed serous membrane. From these evidences we can only arrive at the legitimate and logical conclusion that normal pancreatic juice is promptly and rapidly removed by absorption when brought in contact with the peritoneum. The uniformity with which the detached portion of the pancreas was found atrophied, only corroborates the statements previously made when we considered the same question in connection with external pancreatic fistula.

Another incidental observation of considerable importance was made concerning the danger of gangrene of the duodenum in case the mesentery is detached to any considerable extent. In all of these experiments the duodenum was denuded of its mesentery, and consequently deprived of its direct vascular supply to the extent of from one to three inches, and yet in no case was the duodenum found gangrenous. As in other experiments upon the pancreas, the duodenum showed a marked immunity against gangrene from interruption of its vascular supply. The last experiment is of great importance, as it illustrates that digestion may remain unimpaired even if no pancreatic juice is produced, or in the event of its secretion not gaining entrance into the intestine on account of complete and permanent obliteration of the common or principal pancreatic ducts. The ligation experiments, as well as the internal pancreatic fistula, also corroborate the statement made by some authors, that the introduction into the circulation of normal pancreatic juice is innocuous, and that this abnormal supply is tolerated for two weeks or more without any appreciable ill consequences.

V. Wounds of the Pancreas.

Of all abdominal organs the pancreas is most exempt from injury, both from direct and indirect violence; a circumstance which is entirely due to its remote location, and the ample protection furnished by the vertebral column and the bony walls of the chest. The anatomical relations of the pancreas to numerous and important organs are such that when this organ is injured, the same violence which has produced the injury has also wounded an adjacent and perhaps more important viscus. The frequency with which such grave complications attend wounds of the pancreas, and the profuse hæmorrhage which usually attends such injury, are elements of danger which impart to wounds of the pancreas more than an ordinary degree of gravity.

1. Contusion.

Case 1. Cooper[1] reports the case of a man, aged thirty-three years, run over by a light cart, moving with great speed. No marks of external injury were visible, but the lower left ribs were fractured, and the pancreas was literally smashed, and embedded in semi-coagulated blood. The spleen and left kidney were also ruptured. He died a few days after the accident.

Case 2. Travers[2] observed a case of laceration of the pancreas at St. Thomas' Hospital. An intoxicated woman was knocked down by the wheel of a stage-coach, which, however, did not pass over her. She lived only a few hours. Several ribs were fractured; the pancreas was found completely torn through transversely, the liver was lacerated, and much blood was effused.

Case 3. Störck[3] mentions the case of a woman who was run over by a coach, and who died within a few hours. The pancreas was found completely torn in two, and embedded in a large mass of semifluid blood. Several ribs were fractured, and the liver was also ruptured.

Case 4. M. Le Gros Clark[4] observed an instance of subcutaneous laceration of the pancreas, which occurred in a lad who was also the subject of other severe injuries which speedily proved fatal.

2. Penetrating Wound of Abdomen, with Protrusion of Pancreas.

Case 5. Laborderie[5] reports the case of a girl, aged ten years, who had fallen, while running, upon an open pocket-knife, which inflicted a wound two

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[1] The Lancet, Dec. 31, 1839, vol. i. p. 486.

[2] The Lancet, 1827, vol. xii. p. 384.

[3] Annus Medicus, 1836, p. 244.

[4] Lect. on Principles Surgical Diagnosis, 1870, p. 298.

[5] Gazette des Hôpitaux, No. 2, 1856.

centimeters below the lower border of the rib, and three fingers' breadth to the right of the median line, extending outward for one and a half centimeters, almost horizontal, with a little inclination from above downward. The pancreas was found strangulated in the wound so tightly that not a drop of blood escaped. The author believed that the prolapse was caused by the screaming of the patient. The duct of Wirsung and vessels escaped injury. The abdomen was painless on palpation, and there were no signs of internal hæmorrhage. The knife had entered the abdomen under the lobus Spigelii of the liver, and in its course reached the stomach, cut through the gastro-hepatic omentum, and then penetrated between the liver and pylorus to the pancreas, without injuring any of the many large vessels in the locality through which it passed.

An attempt to replace the gland was only partially successful. The mass was transfixed and tied at its base with a double ligature, and the portion outside of the ligature removed with the knife. After this procedure nausea and vomiting set in, which, however, soon subsided. The wound was treated by the use of cold water applications. On the third day the patient complained of being chilly, and the abdomen became somewhat tympanitic and tender on pressure. These symptoms soon subsided, and the ligatures sloughed through, leaving a granulating surface, which healed in fourteen days. Recovery was complete in three weeks.

REMARKS.—Hyrtl and Klebs are incredulous as to the prolapse of the pancreas in this case; they believe that the mass ligated and removed was not the gland, but a portion of the omentum. Nussbaum,[1] however, in speaking of visceral injuries of the pancreas, states distinctly that in penetrating wounds of the abdomen in the region of the pancreas, this organ manifests a tendency to prolapse, and that this circumstance facilitates the treatment, as it protects the peritoneal cavity against infection, by plugging the wound, and at the same time affords better access to the bleeding vessels.

CASE 6. Dargau[2] saw a case in which the pancreas protruded through a wound five inches in length, between the last two false ribs, on the left side. The patient was a negro, who had been injured fourteen hours before he came under treatment. The pancreas was replaced, the wound closed, and the patient made a good recovery.

CASE 7. Caldwell[3] reports the following remarkable case: In 1816, a negro was stabbed in the left side, and "an oblong body, between three and four inches in length, was observed to have protruded." Drs. Roberts, Heard, and Caldwell supposed the protruded part might be mesentery, omentum, or lung substance; but, on a more minute examination, that opinion was changed

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[1] Die Verletzungen des Unterleibes, 1880.

[2] Medical and Surgical Reporter, Aug. 22, 1874.

[3] Transylvania Journal of Medicine, 1828, vol. i. p. 116.

to the belief that it was the small extremity of the pancreas. The protruding part was in a gangrenous condition, and was removed with the knife. The patient soon recovered. The gentlemen who treated the case, "thinking it almost impossible that the pancreas could escape through a part of the diaphragm and between the ribs," made a critical examination of the part removed, which resulted in their *thorough conviction* that the tissue removed was a portion of the pancreas.

Case 8. Kleberg, who, together with Dr. Wagner, Jr., examined the specimen of pancreas microscopically, reports the following case:[1] A. S., aged sixty, a discharged soldier, of powerful frame, and a drinker, was surprised while committing a burglary, and cut in the abdomen with a knife from below upward, while stooping over. He was carried into the surgical wards of the hospital at 6 A.M., having a cut in the abdomen running horizontally about twelve inches in length, between the navel and lower border of the ribs on the right side. Protruding from the wound was a brown-red body about three inches long by two inches in width, of a doughy consistence and covered by a smooth membrane. Immediately after entering the hospital he had a normal passage through the bowels; pulse 72; no pain. The stomach, intestines, and liver could be excluded on examining the appearance and physical properties of the projecting body. There was no fat, as would have been the case had it been the omentum of such a corpulent person. The prolapsed body was compact and homogeneous, could not be separated into layers, and presented no dilated vessels. It was, therefore, taken to be the head of the pancreas.

As reposition of the protruding part did not appear advisable, on account of a possible constriction, and as the consequences could not be foreseen, the part was fixed in the wound with two Karlsbad needles, which were passed through the sides of the wound and the protruding part; a silk ligature was then passed around the pedicle of the protruding part and the end cut off with one stroke of the knife; the profuse oozing of blood was stopped by tightening the ligature. The stump was touched with liq. ferri sesquichlor., and cold applications made over the whole abdomen. There was no fever, peritonitis, or disturbance of digestion in the course of the recovery. The needles and sutures were removed on the fourth day; the stump had become adherent to the edges of the wound. The stump and ligature came away on the tenth day. The patient left the hospital twenty days after admission, with a three-cornered depressed scar. As he was perfectly well nourished during the entire time, it is probable that the caudal extremity of the gland was removed and that the portion of the gland remaining, with the excretory duct, performed the functions of the gland adequately.

Case 9. Assistant Surgeon J. G. Thompson, 77th New York,[2] reports the case of "a soldier, name unknown, who was wounded at Cedar Creek, October 19, 1864. The ball entered the right side, below the ribs, and emerged on the

[1] Langenbeck's Archiv für Chirurgie, vol. ix. p. 523.

[2] Medical and Surgical History of the War of the Rebellion, part ii. vol. ii. Surgical History, p. 158.

left side. He was removed to the Taylor Hospital, at Winchester. While straining at stool, two days subsequently, a hernia of the pancreas occurred of the size of a hen's egg. A silver wire was passed about the pedicle by which it was attached, and twisted tighter each day for about a week, until it became very small, and was snipped off with scissors. No especial symptoms supervened, and by the last of November the patient was in a fair way toward recovery, and was moving about the hospital. In December he was still doing well."

Case 10.[1] Private William Freshwater, Co. F., 66th Ohio, received wounds of the abdomen, left forearm, and neck, at Port Republic, June 9, 1862. He way conveyed to Port Royal, arriving on the 13th, and on the 14th was sent by rail to Washington, and admitted, on the 15th, to Judiciary Square Hospital. He was placed in a ward under the charge of Acting Surgeon D. W. Cheever, who states that "a ball had entered one and a half inches outside the left nipple, on a level with the seventh rib, and could be felt under the skin near the spinous process of the last dorsal vertebra. Some viscus, thought to be the lower tip of the lung, protruded at the wound. He died in two days (June 17th) with symptoms of peritonitis. Post-mortem: The ball had pierced the diaphragm without touching the lower lobe of the lung; there was no perforation of the intestines, but they were glued together by peritoneal inflammation. The pancreas protruded at the wound."

3. Gunshot Wounds.

The only cases of gunshot wounds of the pancreas that I have been able to find are reported by Otis.[2]

Case 11. Private J. Koprieau, Co. B., 51st New York, aged thirty-two years, was severely wounded at the battle of the Wilderness, May 5, 1864, and was at once taken to the field hospital of the 2d division, Ninth Corps. As the patient could not talk English, the history of the case is quite imperfect. Assistant Surgeon J. C. McKer furnished the following description, which I have abbreviated without omitting essential facts:

The patient came under his care May 25, 1864, when it was ascertained that he was suffering from a gunshot wound of the back, the ball entering about six inches to the left of the spinal column, having pushed below the eighth or ninth rib. It was evident that the ball had entered the abdominal cavity, but its course could not be ascertained. Patient's general health was apparently good, and he seemed to suffer but little pain from the injury. Appetite good, bowels regular, urine slightly suppressed and somewhat highly colored. Pulse normally full, but slightly irritable. The patient was ordered quinine, whiskey, nourishing diet, and two doses of acetate of potassa. No noticeable change appeared for about one week, when a severe hæmorrhage occurred, apparently venous, from the external wound, which was soon arrested by the use of compresses and styptics. About six hours afterward a quantity of urine was voided, which was thickly mixed with blood. These hæmorrhages

[1] Ibid., page 158.

[2] Ibid., page 159.

continued to recur two, three, and four times daily till death, the urinal discharge being very frequent, and always bloody. Death resulted June 5. 1864.

Post-mortem examination revealed the following: A minie-ball entered at the middle portion of the eighth rib, fracturing the same, passed through the center of the spleen towards the pancreas, penetrating this also in a nearly transverse direction, and (probably a few days before death) sinking toward the splenic artery, tearing it, and lodged at its origin from the cœliac axis; the lung was found emphysematous. The ball was found embedded in the pancreas in a pouch between the sloughing artery and vein. The specimen is preserved as a wet preparation in the Army Medical Museum, and is marked No. 2430. (Fig. 21.)

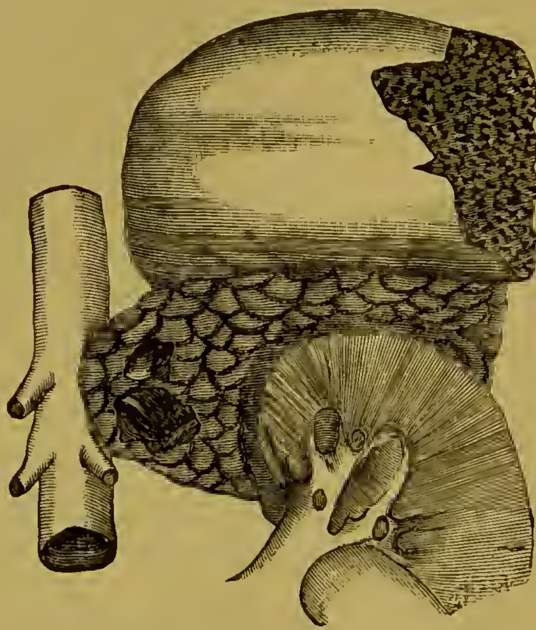

Fig. 21. A wet preparation of portions of spleen, pancreas, kidney, and cœliac axis, showing musket-ball embedded in the pancreas.

Specimen, Army Medical Museum, No. 2430.

Case 12. Corporal A. B. Jones, Co. D., 5th Vermont, aged twenty-seven years, was wounded at the battle of the Wilderness, May 10, 1864, and laid on the battlefield one day and night; was then removed to the field hospital, from there carried by boat to Washington, and jolted over a rough road of two miles to the Lincoln Hospital, which he reached about two o'clock in the morning of the 25th. Was seen a few hours afterward by Acting Assistant Surgeon T. L. Leavitt, who found him suffering great agony. On examination it was found that the ball had entered one line to the left and below the ensiform cartilage. passing through the abdominal cavity, and making its appearance under the

skin just above the crest of the ilium posteriorly, where it was excised at the field hospital. Pulse quick and exceedingly feeble, abdomen distended and tympanitic. Opium was administered and the patient took liquid food freely. About noon of the same day the symptoms improved, wound suppurating nicely. About four o'clock was conversing with nurse, apparently in good spirits, without very great pain; in about five minutes afterward was *in articulo mortis*.

The autopsy showed the ball to have perforated the inferior curvature of the stomach, and, strange as it may seem, although an orifice was made directly through the walls of the stomach large enough to readily admit two fingers, no inflammation or even congestion could be detected, except in the immediate locality of the wound, which was beginning to suppurate. Evidently the stomach was also uninjured in its functional capacity, as was witnessed by the reception and digestion of food during life. Some branches of the gastric artery were severed, and about an ounce and a half of dark uncoagulated blood was found. The pancreas was perforated at about its middle, but, except in the immediate track of the ball, gave evidence of no departure from its healthy standard; the intestine and colon were pushed aside during the passage of the ball and were uninjured; the omentum was found in a state of partial decomposition and closely adherent to the small intestine. Liver and spleen healthy. General peritonitis had prevailed and was undoubtedly the cause of death. In this case life was sustained for a period of fifteen days, notwithstanding the serious injury of a vital organ and the exposure to most unfavorable circumstances and depressing influences.

Case 13. Private William P. B., Co. A., 44th Georgia, was wounded near Fort Stevens, in General Early's demonstration on Washington, July 12, 1864, by a cylindrico-conical musket-ball, which entered below the spine of the left scapula, an inch from the shoulder-joint, and penetrated the chest. He remained a prisoner on the field, and was conveyed to Lincoln Hospital, a few miles distant, being admitted on July 14th. He was examined by Dr. Leavitt, who found that emphysema extended over the entire left chest, that respiration was painful, but not otherwise difficult, and that there was paralysis of motion of the left arm. There was little change in the progress of the case until the 18th, when the pain in the side became severe, and was somewhat relieved by sinapisms. Following day, dullness over posterior left chest, also extreme dullness in the præcordial region and the heart was forced over to the right side. There was dullness too at the base of the right lung, with indistinct respiratory murmur. On the 20th, jaundice was very pronounced. On the 21st, profuse hæmorrhage from the nose and mouth occurred, bleeding coming apparently from the lung. Pulse at this time very weak and thready; jaundice extreme. On the 22nd, there was much pain in the left side, dyspnœa, consciousness perfect, pulse failing; death at noon, July 24, 1864, twelve days after the injury.

At the autopsy the wound was traced from the entrance in the scapula through the fractured fifth rib, the track passing downward, inward, and backward, through the lower lobe of the left lung, the diaphragm and the left

lobe of the liver to the head of the pancreas, where the ball was found lodged in the head of the viscus, at the angle formed by the cœliac axis with the aorta. The lower lobe of the right lung was hepatized; the left lung carnified, collapsed and compressed by a large accumulation of black fluid blood. The pancreas was rather large—seven inches long; weight, with ball, five ounces. There was nothing abnormal in its appearance, except the presence of the foreign body. On examining the pancreas microscopically no deviation from the normal structure was found in sections made from the tissue taken from the left end or tail of the viscus and from the middle part. In close contiguity to the ball was a fine network of fibrillated tissue. As hardened in alcohol the specimen offers no indication of vascular engorgement having existed. The specimen is preserved in the Army Medical Museum, and is marked No. 2884. (Fig. 22.)

FIG. 22. Pancreas with a conoidal musket-ball embedded in its head.
Specimen, Army Medical Museum, No. 2884.

REMARKS.—Not in a single instance of the thirteen cases of injury of the pancreas, as reported above, did symptoms during life first point to this organ as the seat of lesion. In all cases where the result was fatal, death was not attributable to the visceral lesion of the pancreas, but was always referable to injury of some adjacent organ. With the exception of cases of prolapse of this organ through a penetrating wound of the abdomen, the diagnosis and treatment of injuries of the pancreas will come under the observation of surgeons only in an incidental manner in the treatment of more tangible and graver lesions within the abdominal cavity. Contusion and laceration of the pancreas as independent conditions are not necessarily fatal injuries, and spontaneous recovery may take place, followed by absorption of the crushed portion of the organ, and atrophy of that portion of the gland which has become physiologically detached from the intestinal tract by the injury or

its direct consequences. Crushing of the pancreas is usually not attended by hæmorrhage, and in laceration of the organ the danger from this source is much less than in cases of incised wounds.

As modern surgery dictates not only the justifiability but the absolute necessity of treating penetrating wounds of the abdomen, where visceral injury is suspected, by abdominal section, the surgery of the future will undoubtedly deal with contusions and lacerations of the pancreas in connection with visceral injury of some of its adjacent organs. If, in exploring for injuries in this region, the pancreas should be found extensively crushed, it would be good surgery to remove the crushed portion, after preliminary ligation of the organ on each side of the comminuted portion.

Ligation of the pancreas can be safely done with a single catgut or silk ligature, as the friable texture of the organ will permit of burying the ligature deeply, a circumstance which will guard against slipping of the ligature. In not a single instance where this method of ligation was resorted to in the experiments on animals, was secondary hæmorrhage from inefficiency of the ligature observed. If the pancreas is lacerated, each end of the organ should be ligated for the purpose of arresting or preventing hæmorrhage, as well as to guard against extravasation of pancreatic juice into the abdominal cavity.

The results obtained by experiments on animals, as detailed above, have demonstrated in a satisfactory manner that normal pancreatic juice when brought in contact with the peritoneum does not produce inflammation, but is promptly removed by absorption. In the experimental work we always had the advantage of dealing with a normal serous surface, the absorption capacity of which had not been impaired by antecedent pathological conditions, as would in all probability be the case in the operative treatment of injuries of the pancreas. At the same time there can be no doubt that the presence of crushed pancreatic tissue and pancreatic juice in the peritoneal cavity, after abdominal section, would greatly enhance the danger of traumatic infection. For this reason, if for no other, the former should be removed and the escape of the latter prevented by ligation of the pancreas on the side, or each side, of the crushed or lacerated portion.

The cases of protrusion of the pancreas seem to establish the fact that a portion of this viscus may be separated by violence from

the splenic artery and other important attachments, and may prolapse through an external wound, and under such circumstances be removed without hazardous consequences. In most cases the prolapse followed some time after the injury, from a sudden increase of intra-abdominal pressure, as coughing or straining at stool.

Klebs and Hyrtl's objection to the possibility of a hernia of the pancreas, can find a plausible support only by assuming that the relations of the pancreas have not been disturbed. If, by the violence which produced the penetrating wound, the attachments of the organ are severed, or in case the attachments have been abnormally loose, or the duodenum is supplied with a long mesentery, there is no tenable reason why the pancreas should not occasionally be found protruding through the external wound. Cases are on record where the pancreas constituted one of the contents of a diaphragmatic hernia, and an instance is reported where it formed a part of the intussusceptum in a case of invagination of the bowel (Bandl).

The treatment of prolapse of the pancreas will depend upon the pathological condition of the viscus at the time the patient comes under the care of the surgeon. If the prolapse is recent and the organ presents no indication of inflammatory or other changes, it should be thoroughly disinfected and replaced. It is of the greatest importance not to resort to violence in effecting reduction, as irreparable damage may be inflicted by resorting to more than the gentlest force. When reduction is not readily accomplished, the wound should be enlarged. If the pancreas is in a condition of inflammation or gangrene, the parts should be thoroughly disinfected and the organ pulled further into the wound until healthy tissue is reached, when a ligature is applied and the diseased portion removed with the knife or scissors. After another thorough disinfection the stump is dropped into the abdominal cavity and the external wound closed. Thorough primary removal of infected tissue is the only safety against subsequent extension of the infection to the peritoneal cavity, and the only guarantee for primary union of the abdominal wound.

In gunshot wounds of the pancreas we have no guiding symptoms upon which to base even a probable diagnosis. The point of entrance and exit of the ball, and its probable course, are the only facts which may point to the pancreas as one of the injured organs.

In four of the five cases, the projectile penetrated posteriorly in the space between the angle of the left scapula and the angles of the ribs, and passed through the diaphragm and the solar plexus; in one the ball entered anteriorly near the tip of the xiphoid cartilage, and was believed to have passed through the stomach.

It is a notable and somewhat significant fact, that in all cases where life was prolonged for more than twelve days, the pancreas appeared to have undergone but little or no pathological change in the vicinity of the visceral wound. Although in all cases the track of the ball did not remain aseptic, the inflammatory changes did not materially affect the parenchyma of the gland.

In case 13 the formation of a capsule around the bullet had already been initiated, and if the patient had lived, there is every reason to believe that the foreign body would have become encysted in the parenchyma of the pancreas.

Gunshot injuries of the pancreas, when they come under the observation of the surgeon as an independent lesion, or as a complication of other visceral injuries in cases of penetrating wounds of the abdomen treated by laparotomy, should be treated in the same way as a contusion or laceration of the gland. The results obtained by the experiments have shown that if only a comparatively small portion of the pancreas remains in physiological connection with the duodenum, this portion of the gland retains its normal structure and its physiological function; which, in all of the experimental cases, was found adequate to supply the requisite quantity of pancreatic juice necessary for the maintenance of normal digestion.

While the surgeon may unhesitatingly remove the tail and a portion of the body of the pancreas without fear of any immediate or remote ill effects, great care must be exercised in operating in the vicinity of the head of the pancreas to preserve the integrity of the common duct, and as much of this portion of the organ as may appear compatible with the condition which necessitated the operation.

The results of the experiments made with a view to ascertain how much of the mesentery of the duodenum can be detached without causing gangrene of the bowel have been such as to encourage a conservative plan of treatment when operating in close proximity to the intestine. The observations made in this direction have shown that it is comparatively safe to detach a portion of the

mesentery even to the extent of one to three inches, a procedure incomparably easier and much safer than enterectomy combined with partial excision of the head of the pancreas. I wish again to emphasize the fact that complete extirpation of the head of the pancreas with the common duct is never justifiable, and that operations upon this portion of the gland for injury or disease must be limited to partial excision of the head, with preservation of the common duct.

VI. Acute Pancreatitis.

Acute idiopathic pancreatitis is an exceedingly rare affection; only a few well-authenticated cases of the disease have been reported. A brief consideration of this affection is necessary in connection with our subject, for the purpose of calling attention to a few of the most constant and prominent symptoms which characterize the disease, inasmuch as all suppurative lesions of this organ, which are of special interest to the surgeon, are preceded by inflammation. The disease originates either primarily in the inter-acinous connective tissue of the organ as a pancreatitis, or it occurs as a secondary disease from extension of a peripancreatitis to the substance of the gland. Haller and Klob have given an accurate clinical description of a case observed at the Allgemeines Krankenhaus in Vienna, with a careful account of the post-mortem appearances.[1]

Case 1. A gilder, sixty-three years of age, had been suffering from indigestion, which was referred to a defective stomach digestion. Flatulency and vomiting were prominent symptoms. The patient was anæmic, and presented a cachectic appearance; tongue slightly coated, anorexia, epigastrium tympanitic and tender to pressure. Vomiting of a thin, yellow, bitter fluid. Slight elevation of temperature; pulse 90; lower extremities œdematous. The same evening vomiting, collapse, and great pain in epigastrium, extending over the abdomen. During the night obstinate vomiting, traces of blood in the ejected matter; urine dark colored, contained no albumen. Next day vomiting ceased, but collapse increased, followed by death toward evening.

The autopsy revealed serous infiltration of gray matter of brain and lungs. The stomach was collapsed, its mucous membrane bulging. The posterior wall of the stomach was perforated in three places, the openings being as large as a pea, and funnel shaped, with the larger extremity directed toward the peritoneal surface. The edges of these perforations were quite friable, discolored, and continuous with a fetid abscess cavity, which extended from the posterior surface of the stomach to the spinal column, and from the

[1] Schmidt's Jahrbücher, 1860, vol. i. p. 306.

spleen to the pylorus, in which the pancreas was found as a grayish, discolored, flabby, thin, and exceedingly fragile mass infiltrated with pus. In front of the anterior wall a fringed portion of the bursa omentalis was found, and on the upper border the arteria and vena lienales were seen; the latter was filled with a thrombus. Examined under the microscope the parenchyma of the gland showed that the cells were degenerated, being distended and turbid; acini separated, at some places collapsed, and the spaces between them contained granules and large globules of fat.

Remarks.—The course of the disease was quite acute, terminating in diffuse suppuration and death, after an illness lasting only sixteen days. The absence of disease in any of the adjacent organs, and the advanced pathological changes in the gland, pointed to the pancreas as the primary starting-point of the inflammation.

Case 2. Mayo[1] also gives an interesting description of a fatal case of subacute pancreatitis, with the post-mortem appearances. The patient was a lady, twenty-one years of age; when five months advanced in pregnancy she lost her usual healthy appearance, and gradually became very anæmic. She complained of great thirst, and also suffered much from pain in the epigastric region, which was sometimes so severe as to oblige her to retire to her apartment. After her delivery the thirst remained, and the weakness and paleness increased. Her state and symptoms were like those of persons who have lost large quantities of blood. About five days before death the stomach became irritable, and nothing but rennet-whey in small quantities was retained. She died five weeks after delivery. Upon inspecting the body, the viscera generally were found pale and bloodless. Besides serous effusion on the membranes of the brain and the abdominal organs, no pathological changes were observed, except that the pancreas was throughout of a deep and dull red color, which contrasted very remarkably with the bloodless condition of other parts. It was firm to the touch externally, and when an incision was made into it, the divided lobules felt particularly firm and crisp.

Case 3. Haidlen[2] reports the following case from Fehling's private practice: A woman, aged thirty-three years, became pregnant, and during the period of gestation had considerable gastric disturbance and headache. She remained well three weeks after delivery, when there was some hæmorrhage. A little later she had two attacks of pain in the region of the stomach, and five and a half weeks after delivery she had a very severe attack of pain in the pyloric region, accompanied by vomiting. There was no elevation of temperature; the pulse was 100 to 104, and regular. The epigastric region was sensitive to pressure, but there were no symptoms of peritonitis; the skin was pale and not jaundiced. The patient seemed somewhat collapsed. In the afternoon of that day she seemed worse, the skin was paler, the pulse more rapid, and the vomiting had ceased. Physical examination showed marked

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[1] Outlines of Human Pathology, London, 1836, p. 409.

[2] Centralblatt für Gynäkologie, Sept. 29, 1884.

swelling of the abdomen, and great tenderness over pyloric region. No pelvic disturbances. On the following day the patient was better, but the symptoms returned, and she died, in collapse, in ninety-six hours.

The autopsy showed that there was no peritonitis, though a small amount of a dirty, bloody-looking fluid was found in the lower part of the peritoneal cavity. The organs, with the exception of the pancreas, were normal. The pancreas had undergone considerable changes: it was larger, thicker, and broader than normal, and its normal color was retained in only a few places; it had changed almost entirely to a brownish-red, blood-suffused mass, containing a small clot of blood on the anterior surface, in contact with the mesentery, but there was no perforation anywhere. The adjacent portion of the mesentery was suffused with blood. Ziegler, who made the microscopic examination, pronounced the case one of acute pancreatitis, and stated that the duct of Wirsung was somewhat dilated, and that he also found small-celled infiltration of the pancreatic tissue.

Remarks.—The immunity of the pancreas from disease is attributed by Gross to the singular structure of this organ, to its concealed situation, and to the absence of everything like a proper envelope.[1]

The first two cases may serve as types of the two distinct forms of inflammation of the connective tissue of the pancreas, the suppurative and interstitial. Another, the parenchymatous form, is occasionally met with in the puerperal state, in cases of typhoid fever, pyæmia, yellow fever, and other acute infectious diseases, the post-mortem appearances of which are illustrated by case 3. In this form the pancreas is red, swollen and œdematous. In this variety the most prominent microscopical lesion consists in swelling and undue granulation of the glandular epithelium, and hyperæmia.[2]

In the first case the symptoms were acute, and the disease terminated in death in the short space of sixteen days. The suppurative inflammation beginning in the interstitial tissue, involved the entire gland, and extended by continuity to the para- and peri-pancreatic tissue, giving rise to a diffuse and acute abscess. The termination is sufficient evidence that the inflammation was produced by a specific cause—the pus microbes. In the second case the primary seat of the inflammation was the same, but the process assumed a subacute character, and terminated in a hyperplasia of the connective tissue. The most prominent symptoms in both cases were severe pain in the epigastrium, progressive anæmia, and vomiting. In both cases the pain assumed a neuralgic character. The pain was referred to

[1] Elements of Pathological Anatomy, Philadelphia, 1857.

[2] Delafield and Prudden, Pathol. Anat. and Histol., New York, 1885, p. 369.

the region of the cœliac plexus, radiating from there over the abdomen. Neuralgia of the cœliac plexus is one of the most constant symptoms of disease of the pancreas, as Klebs alludes to it as being present eleven times in fifteen uncomplicated cases. Atrophy of the cœliac plexus is mentioned by Klebs as the cause of the neuralgia.

A high degree of anæmia was apparent in both cases from the extensive area of tissue which was found in an œdematous condition, as well as from the statement of Mayo, that his patient presented the appearance of a person who had suffered from repeated and severe hæmorrhages. As the pancreas is not concerned directly in the function of hæmatogenesis, we can only explain the constancy with which this symptom is mentioned by assuming that the anæmia was due to imperfect digestion and assimilation, caused by an arrest of pancreatic secretion. Vomiting was an early and troublesome symptom in the first case, but appeared only toward the close of the disease in the second case. No reference is made to the condition of the stools in either case. The presence of undigested fat in the stools is, however, one of the rare symptoms of disease of the pancreas. Klebs states that in three cases where this symptom was present, the ductus Wirsungiani was either entirely or partially obliterated, while in a number of cases where the duct was in the same condition the stools remained normal.

VII. Chronic Interstitial Pancreatitis, or Sclerosis of the Pancreas.

This lesion consists in an increase of interstitial connective tissue, which may affect the entire organ or remain limited to some particular portion, more especially the head of the gland. During the early stages of the disease the organ is enlarged, more vascular and firm, while later the cicatricial contraction of the interstitial deposit produces atrophy of the parenchyma, with a corresponding diminution in the size of the organ. This form of inflammation of the pancreas is of particular interest to the surgeon, as the cicatricial contraction may produce secondary changes in the pancreatic or bile-ducts, an occurrence which would indicate a resort to surgical measures for the relief of immediate symptoms due to retention of the secretions.

The causes which produce sclerosis are often obscure, but usually referable to an antecedent affection in some of the organs

adjacent to the pancreas, as the peritoneum, subperitoneal tissue, duodenum, the common bile-duct; or to pancreatic lithiasis, where the primary cause is in the pancreas itself. The connective tissue proliferation destroys the parenchyma by compression, and constitutes one of the causes of stenosis of the pancreatic duct.

Case 1. Todd[1] observed this condition in a girl fourteen years of age, in whom the head of the pancreas and the neighboring connective tissue were the seat of the disease. This case is of unusual interest, as the contraction of the cicatricial tissue produced obstruction of the common bile-duct by compression, which caused a dilatation of the bile-ducts behind the seat of obstruction, converting them into a large sac, which was located behind the duodenum and reached downward as far as the sacrum, and laterally from one kidney to the other.

Case 2. O. Wyss[2] gives a description of another case in point. A man, fifty years of age, became deeply jaundiced and had three or four loose, clay-colored stools daily. He died after an illness of four and a half months' duration. At the autopsy the liver was found enlarged and of a deep olive-green color. The gall-bladder and bile-ducts were much dilated and contained inspissated bile. The common bile-duct entered the head of the pancreas four centimeters before its termination in the duodenum and traversed the indurated portion of the organ for a distance of two and a half centimeters. At this point the duct was found so much contracted that only a fine probe could be passed through it. The common pancreatic duct was dilated, also its branches, which at some points were dilated in the form of cysts, varying in size from that of a hempseed to that of a hazelnut. Wyss attributed dilatation of the common duct to compression by one of the smaller cysts in the head of the pancreas, but it is more than probable that the dilatation was due to the cirrhotic contraction of the organ.

Case 3. That icterus is not a constant symptom of this condition is illustrated by the following case, reported by Claessen: A man, thirty years of age, had been subject to indigestion, constipation, and severe pain in the episgastrium for several years. After his death, it was shown at the autopsy that the head of the pancreas and the acini were yellow, and the inter-acinous connective tissue abundant, and yet the duct of Wirsung and the bile duct were not contracted.

Remarks.—The surgical treatment of sclerosis of the pancreas can only apply to secondary lesions which result from stenosis of the pancreatic or bile-ducts, and distention of these passages by accumulations of the secretions. Such an occurrence is most likely to take place when the disease affects the head of the pancreas, as

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[1] Dublin Hospital Reports. vol. i.

[2] Virchow and Hirsch's Jahresbericht.

the cicatricial contraction in this locality may cause stenosis of either the duct of Wirsung, the common bile-duct, or both. Any operative interference in these cases will be of necessity limited to an attempt to secure an artificial outlet for the retained secretion. The restoration of the permeability of the natural outlet by any method of treatment is entirely out of the question.

The tendency of the disease is to aggravate the obstruction as cicatricial contraction progresses. The history of all these cases pointed to an impairment of digestion as the principal clinical feature in each instance. It is, therefore, of considerable importance to examine carefully into every obstinate and obscure case of indigestion, with a view to eliminate the possibility of organic disease of the pancreas as the cause of the derangement of digestion. In cases of permanent retention of the bile or the pancreatic juice caused by cicatricial compression of the bile-duct or the pancreatic duct, the earlier symptoms will have reference to a history of obstinate indigestion, progressive in its character. If, on the other hand, the obstruction is produced by the impaction of a calculus, the previous history points to attacks of sudden and severe pain, and other symptoms indicative of the passage of a calculus along the excretory duct.

In case of biliary retention cysts, as represented in case 1, the establishment of an external biliary fistula would result in a permanent fistula, as the impermeability of the bile-duct would preclude the possibility of reëstablishing, by an attempt of any kind, the normal communication between the dilated bile passages and the intestine. Such an operation would remove only the urgent symptoms due to retention and absorption of bile, but would leave unchanged the primary cause of the retention, and would exclude, permanently, the bile as a digestive fluid from the alimentary canal.

As the obstruction is permanent and irremediable, the operation which suggests itself as fulfilling the urgent indications, as well as preventing remote ill consequences, is the formation of a new outlet for the bile into the intestinal canal, by establishing a permanent fistula between the duodenum and the gall-bladder, or between the duodenum and the dilated bile-ducts. Duodeno-cholecystostomy has a future in all cases of permanent and incurable obstructive lesions in the bile-duct, and will become an established operation as soon as it has been perfected by an improved technique.

My experiments on animals have demonstrated that physiological detachment of any portion of the pancreas is invariably followed by degeneration and atrophy, irrespective of the particular method by which this detachment is effected; consequently it is only reasonable to assume that permanent obliteration of the pancreatic duct by cicatricial contraction is always followed by degeneration of the parenchyma of the gland on the distal side of the seat of obstruction.

It is on this account that stenosis of the pancreatic duct is seldom followed by dilatation of the duct to any considerable extent on the distal side of the constriction, and even more seldom by the formation of a cyst. A retention cyst can result from obstruction only so long as secretion has not been entirely suspended, and when, at the same time, absorption of the pancreatic juice does not take place, on account of further extensive pathological changes in the structures which perform this function when the gland is otherwise in a normal condition.

As the physiological detachment by obstruction of the common pancreatic duct caused by cicatricial contraction is invariably followed by complete destruction of the parenchyma of the contributory portion of the gland, it is evident that the surgical treatment of a cyst of the pancreas in such cases can be indicated only when the swelling becomes, in itself, a source of serious inconvenience and pain. The proper treatment in all such cases consists in the formation of an external pancreatic fistula by abdominal section. There is no danger, in such instances, of the fistula remaining permanent, as the glandular tissue which might remain at the time of operation will, in the course of time, disappear by degeneration and absorption. As in animals, so in man, the health of the individual after gradual atrophy of the pancreas will depend upon the physiological capacity of vicarious organs, in each particular case, to assume the functions of the pancreas.

In recapitulation, it may be stated that cirrhosis or chronic interstitial pancreatitis sometimes produces stenosis of the bile-duct or the pancreatic duct, and that, when the obstruction is followed by retention of the secretions, an operation becomes always necessary in biliary retention, which should be treated by establishing a new outlet for the bile into the duodenum; while the formation of an external pancreatic fistula in cases of cyst of the pancreas, becomes

necessary only when the presence of the swelling in itself has become a source of sufficient pain and discomfort to warrant treatment by abdominal section.

VIII. Gangrene of the Pancreas.

One of the terminations of acute inflammation of the pancreas is gangrene. Cases have been reported where spontaneous recovery followed elimination of the necrosed organ through the alimentary canal. If spontaneous recovery in this condition is possible, it would seem plausible that a timely removal of the necrosed organ by surgical interference would add to the chances of recovery; consequently we shall add gangrene to those diseases of the pancreas which should be treated by operative measures.

Case 1. Trafoyer, of Hernals, treated a patient suffering from what appeared to be a passage of gall-stones. During the course of the disease the patient passed, per rectum, a solid mass, the nature of which could not be readily ascertained. This mass was sent for examination to Rokitansky, who found in it gall-stones and a large part of the pancreas in which the duct was plainly visible. Rokitansky believed that a portion of the pancreas had become invaginated into the duodenum and had sloughed. Nothing could be ascertained concerning the subsequent history of the case.[1]

Case 2. Reported by Chiari.[2] Female, aged forty-six years, who had been subject to occasional attacks of pain in the stomach. She was seized suddenly with severe pain in the abdomen, followed by vomiting and other symptoms of diffuse peritonitis. Toward the close of the disease she had a chill, and vomited a black, very offensive fluid. At the necropsy the pancreas was found separated from all its attachments and of a brownish color. The duodenum and transverse mesocolon were perforated; the bursa omentalis contained an offensive sanious fluid, consecutive to diffuse peritonitis. The pancreatico-duodenal artery was eroded.

Case 3.[3] Patient, a man thirty-eight years of age, was attacked with symptoms indicative of cholelithiasis, followed by symptoms of obstruction of the bowels, which lasted for a number of days, and subsided only after the passage, per rectum, of the greater portion of the necrosed pancreas. The patient recovered.

Case 4. Israel reports a case of necrosis of the pancreas in a patient suffering from diabetes mellitus.[4] The autopsy showed a fluctuating tumor between the stomach and transverse colon, which revealed itself as a cyst, with

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[1] Allgem. Wiener Zeitung, No. 29, 1862.

[2] Wiener Med. Wochenschrift, Nos. 6 and 7, 1881.

[3] Ibid.

[4] Virchow's Archiv, vol. lxxxiii. p. 181.

thick walls firmly adherent to the intact head of the pancreas. The cyst contained 300 cubic centimeters of a clay-colored fluid, in which crystals of hæmatodin and the necrosed body and tail of the pancreas were found. Israel attributes the cause of the destructive process to an inflammation of the peripancreatic tissue, which had given rise to repeated hæmorrhages into and around the pancreas. The disease of the pancreas, he holds, was not the cause, but the effect of the diabetes.

Case 5. Prince[1] reports the following case: A man, twenty-two years of age, during a violent exertion, was taken with severe pain in the abdomen, followed by pain in the epigastric region, vomiting, chills, and a sensation of great oppression and uneasiness. In a few days diarrhœa followed, and during the third week he died. At the autopsy the anterior abdominal wall was found firmly adherent to the omentum and intestines; between the intestinal convolutions a chocolate-colored fluid was found. The greater portion of the pancreas was destroyed and converted into a black gangrenous mass. The mesentery of the upper portion of the jejunum, which was adherent to the lower margin of the transverse colon, showed in its folds an accumulation of thick greenish pus.

Case 6. Reported by Rosenbach.[2] A woman, fifty-seven years of age, otherwise in good health, had suffered some time before from pain in the abdomen and constipation, but was soon relieved. Three weeks before she came under observation of the reporter, the same trouble returned. The bowels had not moved for three days; frequent vomiting of greenish fluid; great weakness. On examination, a fluctuating tumor the size of a child's head was detected in the epigastric region, behind the stomach which was considerably dilated. The tumor was immovable. As the symptoms pointed to intestinal obstruction of some kind, and failed to be relieved by enemata, it was decided to perform laparotomy, to which the patient readily consented. The abdomen was opened through the median line, but, as the tumor was not rendered sufficiently accessible, a transverse incision was made over the most prominent part. After division of the mesocolon an effort was made to enucleate the tumor, but the inflammatory adhesions were so firm that the attempt had to be abandoned. An effort was then made to push the stomach upward, but this likewise failed. During these manipulations the tumor ruptured and at first clear, then turbid offensive fluid poured out. The fluid was removed without soiling the peritoneal cavity. The sac was then stitched to the margins of the wound. After suturing the remaining portion of the external incision the opening in the sac was enlarged and drained. The patient died of shock six hours after the operation. At the autopsy the necrosed pancreas was found in the sac. The abscess cavity extended behind the stomach and lesser omentum. The intestinal obstruction was caused by pressure of the swelling upon the small intestine.

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[1] Pancreatic Apoplexy, with a Report of Two Cases, Boston Med. and Surg. Journ., July 13 and 20, 1883.

[2] Centralblatt für Chirurgie, 1882.

Remarks.—The pancreas may constitute one of the component parts of the intussusceptum in cases of invagination of the bowels, as such a case has been reported by Bandl, and the specimen examined by Rokitansky furnishes a similar illustration. The second case reported by Chiari may have been of a similar nature, the invaginated portion having sloughed with the remaining portion of the intussusceptum, leaving the continuity of the bowel unimpaired by adhesions at the point of separation. If, in this instance, the necrosis was due to inflammation, we can only infer that the parapancreatic abscess ruptured into the bowel, and that the necrosed portion of the pancreas was eliminated in this manner, and that subsequently the opening in the bowel was closed. Constipation was a prominent symptom in a number of these cases, and in Rosenbach's case the symptoms of obstruction were so well marked that it was decided to perform laparotomy for its relief. This last case is also of great interest, as the existence of a tumor in the region of the pancreas was diagnosticated during life.

Modern surgery deals extensively with abdominal section for the relief and cure of peritonitis and intestinal obstruction. In searching for the cause of either of these conditions during laparotomy, the pancreas should not be forgotten, and when it is found that the primary disease is located in or around this organ, radical measures should be adopted whenever such a course appears practicable.

Whenever the sac can be stitched to the external incision, this should be done, and the sac opened, disinfected, and drained. Search should be made for the necrosed pancreas, and when found detached, it should be removed. As in most of these cases the retroperitoneal tissue is extensively infiltrated, a counter-opening should be made in the lumbar region above the kidney, and thorough drainage established. If an anterior abdominal fistula cannot be established, the course to be pursued should be the same as in treating a pancreatic abscess under similar conditions.

IX. Abscess of the Pancreas.

At the present time no one familiar with the recent advances in surgery would question the propriety of treating a suppurating cavity by incision and drainage, wherever it might be located. Some of the most valuable recent contributions to surgical literature

describe improved methods in treating deep-seated abscesses. Asepsis and effective drainage are the two cardinal points upon which we have learned to depend in the treatment of abscesses in important organs or cavities. If we can secure and maintain these two essential conditions, we can attack with immunity and a fair hope of success, any abscess, wherever it may be located, and whatever its immediate surroundings may be.

In looking over the literature on abscesses of the abdominal organs, we find that modern surgery has been guided almost exclusively by the teaching of the old master: *Ubi pus—ibi evacuo.* It is somewhat surprising that abscess of the pancreas has never been made the subject of surgical treatment. The two principal reasons for this may be found in the facts that abscess of the pancreas is of rare occurrence, and that the recognition of the lesion, when it does exist, is surrounded by many difficulties. There can be no doubt, however, that in the near future, abscess of the pancreas will be treated on the same principles as suppuration in any other locality.

The remote location of the abscess may offer many serious obstacles to diagnosis and a rational course of treatment; but these difficulties will be overcome by improved methods of examination, and more perfect methods of operation. As suppuration is only one of the terminations of inflammation, abscess, like inflammation, may occur primarily in the gland itself, or it may commence in the para- or peri-pancreatic tissue. If the abscess is endo-pancreatic, it may be bounded and circumscribed by the proper investment of the gland; if, on the other hand, it commences primarily outside of the gland, it appears as a diffuse abscess, which extends to the pancreas by contiguity: in other words, we speak of the abscess as a suppurative pancreatitis, or a suppurative peri- or para-pancreatitis.

CASE 1. Frison[1] reports a case of abscess of the pancreas following suppurative pancreatitis, where the collection of pus did not extend beyond the limits of the gland. An otherwise healthy mulatto, twenty-eight years of age, farmer, was attacked in June, 1873, by icterus with no fever. Appetite diminished. The symptoms were not of sufficient severity to keep him from his work. In August he complained of pain in the right hypochondriac region, which was soon followed by ascites and œdema of legs and scrotum.

[1] Pancreatite suppurée, Recueil de mém. de méd. mil., Mai, Juin. 1876.

He was troubled at this time by an intense thirst, and voided large quantities of urine, which, on examination, was found to contain sugar. The liver was enlarged and the patient emaciated rapidly. No fever or diarrhœa. Stools clay colored. Appetite gradually declined, and the patient died in a state of advanced marasmus. At the autopsy the intestines and stomach were found normal. The pancreas was enlarged to three times its normal size and infiltrated with pus; the splenic end was distended by a large abscess. Gall-bladder and bile-ducts greatly distended. Liver olive green in color and contained three abscesses, but was otherwise healthy in structure.

Remarks.—In this case the symptoms during life pointed to the liver as the seat of the disease. The jaundice was undoubtedly produced by stenosis of the bile-duct, either by a catarrhal inflammation of the duct itself, or compression of the duct by the inflammatory exudation which attended the acute inflammation of the pancreas. The ascites was more likely the result of an inflammation of the peritoneum overlying the pancreas, than of an obstruction to the portal circulation. The suppuration in the pancreas was not attended by an increase of temperature. The diabetes was probably due to the disease of the pancreas, and was not a coincident affection, as a number of cases of diabetes have been reported which occurred in the course of some disease of this organ.

Case 2. Timoteo Riboli[1] reports the case of a woman, aged fifty-seven years, who suffered from impairment of digestion, loss of appetite, emaciation, and attacks of vomiting in the forenoon. The tongue was coated. No fever, but night sweats. Bismuth and magnesia improved the symptoms for a time, but soon the disease became aggravated. Hepatitis was diagnosticated, inasmuch as the patient became icteric and complained of a deeply seated dull pain in the region of the liver and epigastrium. Among a number of colleagues who saw the case in consultation, Tommasini was the only one who believed that the pancreas was the seat of the disease. The patient was emaciated to a skeleton and died of inanition. At the autopsy the pancreas was found distended with pus. Gall-bladder was distended with bile. Liver congested. No other pathological conditions were found which might serve to explain the cause of death.

Remarks.—The course of the disease in this case was again afebrile. The symptoms simulated disease of the liver even more closely than in the preceding case, as no mention is made of the presence of sugar in the urine. The suppuration did not extend into the parapancreatic space.

[1] Schmidt's Jahrbücher, 1859, 2, p. 177.

CASE 3. The following case is described by Dr. James Kilgour:[1] The patient was a man, forty-one years of age, who was treated for several years for what was termed bilious dyspepsia. In March, 1850, when first seen by the reporter, he was considerably emaciated and of a melancholic disposition. A prominent symptom was vomiting, especially in the morning, and about two hours after meals. The matter vomited was a sour, viscid fluid, varying in quantity from an ounce to a quart. Skin dry and of a yellowish hue. No diarrhœa, and the stools contained no bile. Urine of sp. gr. 1.022, normal in quantity, loaded with urates, and contained some fat. Pulse small, 100. No pain in abdomen. On left side, from border of stomach to crest of ilium, abdomen was dull on percussion; on palpation inelastic, nodulated, and of a doughy feel. The area of swelling was not well defined. Neither fluctuation nor pulsation could be felt. During the middle of the month of May, the patient complained of chilly sensations, and the area of dullness increased toward the left. Toward the end of the month the chills disappeared and the abdomen became tender and elastic above. During the latter part of July, the legs became œdematous and the patient was somewhat delirious. Toward the close of the disease he was again attacked by a number of chills and died July 28th.

The autopsy revealed the stomach distended with gas, its walls very thin; pylorus indurated and slightly narrowed. Duodenum softened by inflammation, the portion near the pancreas being converted into a pultaceous mass. Liver normal. Spleen enlarged one-third. Pancreas enlarged to the size of a teacup, its left end being attached to the suprarenal capsule on same side. On incising the pancreas a milky fluid escaped. The entire gland was converted into a single sac, which contained purulent fluid with some cheesy particles and fragments of cellular tissue.

REMARKS.—In this case the symptoms were sufficiently clear to enable an accurate observer at the present time to have made a probable diagnosis of abscess of the pancreas. The obstinate vomiting, with the absence of signs of disease of the liver, and the progressive emaciation, should have led at least to a suspicion of disease of the pancreas.

The location of the tumor was also suggestive of the primary starting-point of the swelling. The abscess cavity was larger than in the preceding cases, and the presence of pus was also suggested by the chills which were present at the beginning and close of the disease. As the abscess cavity was single, this would have been a proper case for surgical treatment. A somewhat uncommon feature in this case was the almost complete absence of pain, a symptom which has been considered by Claessen characteristic of disease of

[1] London Journal, Nov. 1850.

the pancreas. The character of the fluid in the cyst would indicate that it was a mixture of pus and pancreatic juice.

As in other secretory organs, the suppurative process may commence in the duct and extend to the interstitial connective tissue by continuity. This is the manner in which the presence of foreign bodies, such as parasites or calculi in the duct, gives rise to abscess of the pancreas. In the following case the inflammation of the duct and the consecutive interstitial suppurative pancreatitis were atttibuted to the presence of an intestinal worm:

Case 4. Reported by Shea.[1] The patient was a woman, aged twenty-nine years, who complained of abdominal pain, and was jaundiced. After a few days, she improved under a mild alkaline treatment, but about three weeks subsequently again became worse. The pain was in the region of the pancreas. At the same time she suffered from nausea followed by vomiting; jaundice reappeared. Active treatment was resorted to, but she soon became unconscious and died forty-eight hours subsequently. The necropsy showed that the body was fairly nourished and distinctly jaundiced. The lungs were slightly congested at the base. Liver large, pale, and soft. Pancreas enlarged and hard, being the seat of an abscess containing pus. A round worm, seven inches long, was found folded upon itself, lying in and obstructing the pancreatic duct, the larger portion of the worm being in the duodenum. The intestines were healthy. In the absence of any other disease, death in this instance must have resulted from inflammation of the duct and parenchyma of the pancreas, by the irritation induced by the presence of the worm. The jaundice was undoubtedly produced by the same cause.

Remarks.—Positive evidence is wanting in this case to prove that the suppuration was caused by the presence of the parasite, as the worm might have entered the pancreatic duct after death. We have evidence that in many cases ascarides have been found in the ductus pancreaticus, without the presence of abscess or even inflammation. Davaine[2] relates that he has found them present in this locality in four cases, and in none of them had secondary inflammatory changes taken place. Klebs found six worms in one case, four in the head, and two in the tail of the pancreas.

Case 5. Mayo refers to a case that came under the observation of Percival.[3] The patient was a gentleman who had jaundice and bilious vomiting. A tumor appeared at the epigastrium; his strength failed, blood and fetid pus were discharged by stool, and he died exhausted in three months.

[1] The Lancet, November 5, 1881.

[2] Traité des Entoz., p. 115.

[3] Outlines of Human Pathology, London, 1836, p. 409.

At the necropsy the pancreas was found greatly enlarged, and contained a considerable abscess; the ductus communis was obliterated by the pressure.

The class of cases which are of special importance and interest to the surgeon are those diffuse abscesses which take their origin in the parapancreatic connective tissue: extensive collections of pus as we observe them in cases of parapancreatitis purulenta. As the glandular tissue is not primarily affected in these cases, early evacuation and drainage of the abscess cavity would not only preserve the anatomical and functional integrity of the gland, but would also serve as a life-saving measure by securing an early outlet of the abscess contents.

The case reported by Haller and Klob, and referred to under the head of pancreatitis, case 1, furnishes a good illustration of cases belonging to this class.

CASE 6. An interesting case of abscess of the pancreas has recently been reported by Musser.[1] The patient was a male, aged forty-two, shoemaker, who was admitted to the wards of the Presbyterian Hospital, May 12, 1885, and died June 6th following. He was of intemperate habits, but his general health had always been good. His poverty had exposed him to all kinds of hardships. The duration of the present illness was not known, but from his statements it was ascertained that his health had been failing all the spring. He had never received any injury. He was considerably emaciated. He vomited only once, and that was on the day of admission. Marked ascites was observed, but nothing else could be found. He remained in a stupid condition, took but little food, and manifested no signs of pain. No fever, no sweating. Palpation showed the liver and spleen to be normal, while an ill-defined tumor could be felt in the epigastric region. Urine contained a trace of albumen, but no casts. The ascites was so great as to warrant tapping, and this was accordingly done. The abdomen was thirty-six inches in circumference at the umbilicus before tapping. Within eighteen hours after tapping, it had filled entirely, and in twenty-four hours measured thirty-two and a half inches. He died of exhaustion.

After death, by palpation, a fixed mass was detected in the abdomen, extending from the right mammary line, one inch above the umbilical line, directly across to the corresponding line on the left side. Its upper margin was not well defined, but it appeared to be two inches wide. The abdomen was filled with serum in which some lymph floated. The intestines were matted together by recent lymph. The peritoneum showed signs of inflammation. Corresponding to the position of the mass indicated by palpation, the omentum was found matted together, with its inferior border turned upward, and lying across the stomach. This organ was fixed and dilated, its inferior border

[1] American Journal of the Medical Sciences, April, 1886, p. 449.

extending to the umbilicus. The liver occupied its normal position. The transverse colon extended across the abdomen along the lower margin of the stomach, thus permitting the omentum to occupy the position indicated above. Further study of the relations of the abdominal organs revealed the formation of a large cavity containing about a quart of pus. This cavity was formed by the posterior wall of the stomach in front, by the pancreas, duodenum, and transverse colon below, and by an extension, or rather distention, of the peritoneum above and behind. Certainly the pus did not fill the retroperitoneal space or extend into it, and was not in close apposition to the diaphragm or brim. It was situated in the duodeno-jejunal fossa. Adhesions prevented communication with the abdominal cavity and the retroperitoneal space. This abscess cavity communicated with an abscess the size of an orange, situated in the head of the pancreas, its point of rupture into the duodeno-jejunal fossa being in the middle and upper part.

The remainder of the pancreas was made up of dense connective tissue, throughout which there were innumerable pus pockets, varying from a pea to pecan nut in size. The secreting tissue of the organ was not discernible to the naked eye. The ducts were not occluded, but rather dilated, and no calculi were found. The portal vein was filled with a purulent thrombus. The splenic vein was also partially closed by a soft thrombus. The superior and inferior mesenteric veins were completely blocked by laminated thrombi, which were firmly adherent to their walls. On microscopical examination, the pancreas was found to be made up of old and young connective tissue; in the large interstices of the bundles of old tissue, the glandular structure could be readily made out, while the tubules were seen to be in a state of catarrhal inflammation. The intertubular connective tissue was crowded with young cells.

Remarks.—In this case the conditions were favorable for successful treatment by abdominal section, had even a probable diagnosis been made before the extensive and serious complication of thrombo-phlebitis occurred. The symptoms during life simulated cirrhosis of the liver so closely that it was impossible to differentiate between this affection and disease of the pancreas, although an ill-defined tumor could be felt in the epigastric region. In similar cases an exploratory laparotomy should be done for the purpose of making a positive diagnosis, and, when similar favorable conditions are found, it could be followed at once by radical measures, with a view of securing evacuation and drainage of the abscess cavity. In this case the abscesses in the viscus were the result of a purulent pancreatitis; the secondary abscess was the result of perforation into the duodeno-jejunal fossa, followed by suppurative peripancreatitis.

1. Pathology of Abscess of the Pancreas.

Recent investigations have shown the existence of a direct causative relation between the pus microbes and suppuration; hence we must take it for granted that every purulent pancreatitis, peri-pancreatitis, or parapancreatitis is caused by the presence of these germs in the tissues. In case there is no direct invasion, by a loss of continuity, of the hollow viscera in the vicinity of the pancreas, or no direct communication with the external air by a penetrating wound, we must assume that the germs reach the gland through the circulation, and find a favorable soil prepared by some antecedent pathological change. Such conditions may be determined by contusion of the organ, disturbance of the capillary circulation by various causes, or thrombo-phlebitis. Norman Moore reports the case of a female, twenty-seven years of age, who had died of pyophlebitis, and in which, on post-mortem examination, beside the portal, splenic, and vena azygos minor veins, the pancreatic veins were also blocked by decolorized and adherent thrombi.[1]

The same author gives an account of two cases of abscess of the pancreas due to plugging of the pancreatic vessels.[2] He remarks: "Pathologically, the case in which thrombosis of the pancreas was found is interesting as indicating how pancreatic abscess is produced. The much commoner condition of the liver in the other cases shows that, had the first patient survived, the thrombosis would certainly have been followed by abscess. Clinically, the value of the case is that it may, in rare cases, help to explain the seat of an obscure abdominal swelling, associated with fever, which has followed a thrombosis, and which physical examination cannot localize in the liver."

Suppuration always begins in the interstitial tissue, either within the gland or in the connective tissue around it. A suppurative inflammation and formation of an abscess are different stages of the same process. Peripancreatitic suppuration commences, in most instances, in the adjacent lymphatics; the pus surrounding the lymph glands, or forming a small abscess.

In the vicinity of the pancreas these peri-lymphatic abscesses

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[1] Pathological Observations on the Pancreas, St. Bartholomew's Hospital Reports, vol. xviii. p. 207.

[2] Pathological Society's Transactions, p. 210.

are not unfrequently met with as one of the pathological conditions of pyæmia. Thus, an abscess in the pancreas with perforation into the peritoneal cavity, was examined by Perle.[1] Tulpius saw an abscess of the pancreas as a secondary lesion after an attack of malarial fever. Schmackpfeffer observed the same condition after an operation for strangulated hernia, and Portal after extirpation of a testicle. But suppuration in the pancreas sometimes takes place as an independent affection, without the presence of an appreciable infection-atrium, and in these cases we must assume that the essential and specific noxæ are carried along with the circulating blood, and that localization takes place upon a soil prepared for their reception and growth by previous alteration in texture or circulation. In some instances the process begins upon the outer surface of the gland, the pus separating the gland from its attachments. In the case described by Gendrin the pancreas appeared to have been completely detached, and was lying loose in the abscess cavity.

Many of these parapancreatic abscesses do not present well-defined borders; the pus manifests a tendency to burrow in the vicinity of the mesocolon and the retroperitoneal space, and is apt to perforate into the bursa omentalis, or into some other portion of the peritoneal cavity, or, lastly, finds its way into one of the adjacent hollow organs, as the stomach or intestinal tract. Van Derveren reports the case of a female, fifty-nine years of age, who had suffered for thirty years from attacks of gastralgia. At the necropsy, it was ascertained that the indurated pancreas had perforated the posterior wall of the stomach. The opening represented a round ulcer, two and a half inches in diameter, with indurated margins. In this aperture eroded vessels could be seen. The fistulous tract communicated with the pancreatic duct. The stomach and intestines contained blood, but no other evidences of disease could be found. In Percival's case the abscess ruptured into the bowel, the stools containing fetid pus and blood. A similar case was observed by Haggarth.[2]

The suppurative process, however, may extend in an opposite direction, from the stomach to the pancreas.[3] A communication

[1] De Pancreas ejusque morbis, Dissert. Berol., 1837.

[2] Transactions of the College of Physicians in Ireland, vol. ii.

[3] Rokitansky, Lehrbuch der pathol. Anatomie, Wien, vol. iii. p. 168.

between the stomach and the pancreas is sometimes established by perforation of a gastric ulcer in this direction. Around the margins of the ulcer, between the stomach and pancreas, adhesions are formed, an occurrence which prevents extravasation of the contents of the stomach into the peritoneal cavity. A number of the terminal openings of the accessory pancreatic ducts have been observed upon the cicatrized surface of a gastric ulcer. In place of the formation of a permanent pancreatico-gastric fistula as described by Rokitansky, perforation of the stomach in closer proximity to the pancreas may give rise to diffuse and rapidly fatal parapancreatitis or peripancreatitis.

The indirect primary cause of a pancreatic abscess may be due to a calculus in the pancreatic duct. Fournier has recorded a case where, on post-mortem examination, an enormous abscess was found in the head of the pancreas, which contained numerous calculi. The tumor was sufficiently large to be readily detected in the epigastric region during life.

An abscess of the pancreas may also originate in a preëxisting cyst of the organ. Kilgour's case, detailed above, had undoubtedly such an origin. The abscess cavity was as large as a teacup, and contained a milky fluid and caseous particles, which were undoubtedly a mixture of pus and pancreatic juice. The disease was attended by chills and fever, which indicated that the retention cyst had become the seat of an acute suppurative inflammation.

As primary, idiopathic, uncomplicated, purulent inflammation of the pancreas is an exceedingly rare affection, it is of great practical importance in the surgical treatment of such cases to determine, if possible, the predisposing cause or causes, and to remove them or render them inert at the time of operation.

2. Symptoms and Diagnosis.

The presence of pus within the pancreas or in its immediate vicinity is not indicated by any characteristic or positive symptoms. The symptoms always point to the stomach or liver as the seat of the disease. The most prominent and constant symptoms which have been observed are nausea, vomiting of a clear greenish or viscid fluid, thirst, loss of appetite, constipation, progressive emaciation, and distention of the epigastrium.

In almost all cases the patients presented a sallow, cachectic

appearance, and were exceedingly anæmic. Ascites and œdema of the lower extremities were present a number of times. In several instances the inflammatory process in the pancreas extended to the bile-duct, or caused stenosis of the duct by compression; conditions which are followed by biliary retention, a symptom which has usually been interpreted as an evidence of primary disease of the liver or bile-ducts. The progressive anæmia and emaciation, in the absence of other tangible lesions, are symptoms which should always direct attention to the pancreas as the seat of the disease.

Fever was seldom a conspicuous, and never a constant symptom of suppurative pancreatitis. The use of the thermometer in the diagnosis of suppuration in this locality is important, but it furnishes no positive evidence. If the abscess is large, it will be recognized by palpation and deep percussion, as a tumor in the epigastric region. In such cases a probable diagnosis may be made by a careful and systematic physical examination, and by reasoning by exclusion.

An abscess within the gland is always located in the bursa omentalis; a peripancreatic abscess in the bursa omentalis, duodeno-jejunal fossa, or upper portion of the peritoneal cavity; and a parapancreatic abscess in the retroperitoneal space. Inflation of the stomach will often serve a useful purpose in the differential diagnosis of tumors in the epigastric region. In obscure cases, manual exploration of the rectum may add important and sometimes decisive information.

Age is also an important element to be considered in the diagnosis. Most of the cases of abscess of the pancreas were patients of more than forty years of age, and often persons of intemperate habits. Puncture with an aseptic capillary needle will demonstrate the presence or absence of pus, but will not add material information in locating with accuracy the abscess cavity.

Finally, in all cases in which a tumor can be felt in the epigastric region, and a probable diagnosis can be made regarding its benign character, an exploratory laparotomy should be resorted to for the purpose of making an accurate anatomical diagnosis.

3. Prognosis

The prognosis of abscess of the pancreas is always unfavorable. Death is produced by progressive emaciation and inanition, by septic

absorption, or secondary lesions in adjacent organs. In acute, diffuse pancreatic abscess a fatal termination may take place in a few days. One of the great dangers of abscess in this locality is the close proximity of numerous important veins, which become implicated by extension of the suppurative inflammation to their walls, producing a suppurative thrombo-phlebitis, with all its disastrous consequences. Perforation of the abscess into the stomach or intestinal tract is the most favorable spontaneous termination, and has resulted, at least in one instance, in a cure. Perforation of the abscess into the peritoneal cavity would hasten death by inducing a rapidly fatal septic peritonitis.

4. Treatment.

The remarkable success which has attended the treatment of pelvic and abdominal abscesses by laparotomy justifies the hope that, in the near future, the same treatment will be extended to abscess of the pancreas. It is true that the difficulties which surround the treatment of abscesses in this region are many, but they are not insurmountable. Multiple abscesses, disseminated throughout the entire organ, and especially its head, are not amenable to successful surgical treatment. Circumscribed endopancreatic abscess in the peripheral portion of the body or tail of the pancreas should be treated by partial excision of the pancreas, in all cases where the isolation of that portion of the organ can be accomplished without inflicting serious injury on adjacent important organs.

When extirpation is impossible, as when the abscess is located in the head of the pancreas, it must be treated by incision and drainage. This is accomplished in the same manner as in the treatment of a pancreatic cyst. In some instances, the access to the abscess is rendered difficult by distention of the stomach, the dilated organ overlapping the pancreas. In such cases, the stomach must be pushed upward, and subsequent distention guarded against by ordering an absolute diet until the external fistula has been established. The external incision must, in all cases, correspond to the most prominent part of the swelling, as it is of the greatest importance to incise the abscess at a point where the distance between the surface of the abscess and the abdominal wall is the shortest. Incision of the great omentum will be required in all instances.

In making an external fistula in the treatment of the pancreatic abscess, it is essential to protect the muscular and connective tissues of the external incision against contact with pus, by lining the margins of the wound with the parietal peritoneum before the serous covering of the anterior wall of the abscess is stitched to the margins of the wound. One of the greatest difficulties that will be encountered in this operation will be the approximation of the peritoneal surface of the abscess to the margins of the wound, on account of the distance between the surface of the abscess and the anterior abdominal wall; this difficulty will decrease in proportion to the prominence of the swelling.

The size of the external incision will exert an important influence in this direction. If the incision is large, the margins of the wound can be turned inward, thus facilitating the suturing of the anterior wall of the abscess to the margins of the wound. As a rule, it may be relied upon that the anterior wall of the abscess, covered by peritoneum, is quite thick, so that there is little danger of penetrating the abscess cavity with the needle in suturing. Previous evacuation of the abscess cavity by aspiration would diminish the danger of extravasation of pus through the needle punctures, but would also render approximation difficult by the recession of the abscess wall, and should, therefore, not be resorted to unless the swelling is sufficiently prominent to render this circumstance of little importance.

As the suturing of the two peritoneal surfaces is done for the purpose of preventing, in the first place, extravasation of pus into the peritoneal cavity; and, secondly, of securing permanent adhesions between the abscess wall and the margins of the wound, it is important to apply the sutures closely together and to grasp the tissues in such a manner that tearing through of the sutures is impossible. As considerable tension may follow, it would be advisable, in this particular instance, to use silk sutures. As in these cases time is an important element, incision and drainage should immediately follow the suturing.

The remaining steps of the operation will depend upon circumstances. If the abscess is endopancreatic or peripancreatic, simple incision, drainage, and disinfection will answer all indications. If, however, the purulent cavity is located behind the peritoneum and occupies the connective tissue space behind the pancreas, it would

appear rational to drain the abscess posteriorly through one of the lumbar regions above the kidney, by pushing a long closed forceps in a proper direction through the posterior and lateral wall of the abscess until its point can be felt under the skin externally. A small cut in the skin over its point will enable the operator to push the instrument through, and, by dilating its blades, to widen the canal sufficiently to permit the insertion of a large drainage tube. In this manner the most desirable method of drainage—through drainage—could be established, which would render subsequent disinfection and evacuation of the abscess a comparatively easy task. In cases where an anterior pancreatic fistula cannot be established on account of the distance between the abscess and the anterior abdominal wall, we might resort to lumbar drainage and closure of the incision in the anterior wall of the abscess by carefully inverting and approximating the peritoneum over the wound with fine silk sutures.

That the utmost care in the application of antiseptic precautions should be resorted to in the evacuation of pus in this remote region, by any of these procedures, requires no argument. I will repeat that a positive diagnosis of the presence and precise location of a pancreatic abscess is only possible by resorting to exploratory laparotomy, and that this diagnostic aid should be always resorted to when the history of the case and the symptoms and signs presented are sufficiently suggestive to point to a probable diagnosis.

The abscess found and located by abdominal section should be removed by partial extirpation of the pancreas when it is endopancreatic and located near the splenic end of the pancreas. When extirpation is impossible, or when it is located in the head or on the anterior surface of the pancreas, it should be treated by the formation of an anterior abdominal fistula; when located behind the pancreas, by through drainage, or lumbar drainage performed through the abdominal cavity.

X. Hæmorrhage of the Pancreas.

A number of post-mortem examinations have shown that certain cases of sudden death were caused by hæmorrhage of the pancreas, inasmuch as no other evidences were found which could explain the cause of death. In some as yet unaccountable way, even a moderate hæmorrhage in this locality has been sufficient to destroy life.

Zenker has affirmed that in these cases, pressure upon the solar plexus and semilunar ganglion produces paralysis of the heart, to which he attributes the immediate cause of death. If we recollect that tumors of the pancreas, even when of considerable size, do not destroy life in this manner, it seems that the true explanation of the great danger which attends hæmorrhage of the pancreas remains to be ascertained. Practically it is important to differentiate between diffuse hæmorrhage into the substance of the organ and its adjacent tissue, and circumscribed accumulations of blood or hæmorrhage cysts of the pancreas, as the latter condition presents more favorable indications for surgical treatment.

I. Varieties.

a. Hæmorrhagic Cysts.

Case 1. Anger[1] reports a case of hæmorrhagic cyst of the pancreas in a man, aged seventy-two years, who had been a soldier for ten years, during which time he had received several wounds. Later he suffered fracture of several ribs on the left side from a severe contusion, from which injury, however, he recovered completely after three months' treatment in the hospital. No history of syphilis. Five months ago lower limbs became œdematous, and for the last six weeks ascites was present. He was admitted into the Beaujon Hospital February 27, 1865. At this time the following conditions were noted: Œdema of lower extremities; ascites; breathing difficult and stertorous; bronchitis on left side of chest, and hydrothorax on opposite side. Diaphragm pushed upward. Pulse 100, irregular and intermittent. Diarrhœa and loss of appetite. No delirium. Urine contained no albumen. A stimulating treatment was adopted. March 1st. the patient died, the pulse having been for a time exceedingly feeble and intermittent. The breathing toward the last was very labored and the patient was unable to lie down.

Autopsy. Pleuritic effusion on left side, bronchitis. Liver small, somewhat contracted, but not cirrhotic. Serous effusion in pericardium; heart dilated, mitral valve insufficient. On opening the abdomen a tumor, the size of a fœtal head, was found in front of and on a level with the left kidney. This tumor was bounded in front by the stomach and the transverse colon, above by the diaphragm, below by the descending colon, behind by the kidney, toward the median line by the pancreas, and on the outside and above by the spleen. It was loosely connected with the kidney and spleen by connective tissue, in which the vessels of these organs could be readily seen. The tumor was evidently connected with the pancreas. The external surface was irregular and nodulated, the anterior wall of variable thickness. Fluctuation plain.

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[1] Bulletin de la société anatomique de Paris, xl., Année 1865, 2me série, tome x. p. 192.

The vessels of the spleen were intimately connected with the posterior surface and were not easily isolated.

On careful dissection the lobules of the pancreas could be separated from the tumor, but the walls of the cyst contained a tissue which resembled glandular structure. On opening the cyst a considerable quantity of dark fluid blood escaped, which contained a number of small, recent coagula. The inner surface of the cyst was uneven and reticulated, resembling in appearance the interior of the right ventricle. On the surface of the prominences, diverticula could be seen, which were in free communication with the principal cyst. The wall of the cyst was very much indurated and thickened at four or five places. Some of these nodules were fibro-cartilaginous in structure, while others had undergone calcification.

Sections of the cyst wall showed under the microscope nucleated epithelial cells, which resembled in structure the epithelial cells in the pancreas. Acinous groups of glandular tissue were also found. The reticulated structure in the interior of the cyst contained vessels and remnants of the acini. The author came to the final conclusion that the tumor was a cyst, located in the tail of the pancreas. The presence of blood in the cyst was explained by the supposition that, during the progressive dilatation of the cyst, some of the vessels in the connective tissue reticulum had ruptured.

M. Le Dentu, who examined the cyst, also came to the conclusion that the bleeding had taken place into a preëxisting cyst. What symptoms the presence of the tumor had produced during life could not be ascertained, as the patient was being treated for organic disease of the heart, and the tumor was not recognized during life.

Case 2. Störck[1] observed the following case. The patient was attacked during the menstrual period by vomiting, which was followed by coldness of the extremities, palpitation of the heart, and dyspnœa. Soon after this time a pulsating tumor was detected in the epigastric region, which caused considerable pain. The patient also suffered from constipation and attacks of vomiting. She died three and one-half months after the first attack. At the autopsy the entire pancreas was found enormously dilated, weighing with its contents thirteen and one-half pounds. On cutting into it, it was found filled with coagulated blood. Judging from the condition of the coagula, bleeding had occurred at intervals. The weight of the tumor had caused injurious pressure upon adjacent organs. Le Dentu believed that the hæmorrhage was caused by the act of vomiting, and had taken place into a preëxisting cyst of the pancreas.

Case 3. John Parsons[2] reports a case where hæmorrhage into a preëxisting cyst proved fatal after the latter had ruptured into the intestinal tract. The patient was a female, sixty years of age, who had suffered from vague dyspeptic symptoms for an indefinite length of time. When she was examined by the reporter, a fluctuating tumor the size of an orange could be felt in the

[1] Archiv gén. de Paris, Mai et Juillet, 1836.

[2] British Medical Journal, 1857.

epigastrium, just below the greater curvature of the stomach. Emaciation progressed rapidly. The tumor disappeared suddenly, at the same time a viscid, dirty white fluid was discharged through the bowels. The tumor reappeared in a short time, and ruptured a second time into the intestines, followed by hæmorrhage into the ruptured cyst, which proved fatal. At the autopsy, the pancreas was found excavated into a wide canal, which, at either extremity, was dilated into a cyst. The walls of the cysts were of the firmness of cartilage, and the organ was adherent to the stomach, kidney, and colon. Coagulated blood was found in the dilated duct and cysts.

Remarks.—In Anger's case there is room for speculation concerning the origin of the cyst and the source of hæmorrhage. As the cyst had not ruptured and did not remain in communication with the patent pancreatic duct on the proximal side, we can only explain the absence of altered pancreatic juice, or at least the absence of cyst contents previous to the occurrence of the hæmorrhage, by assuming that absorption took place as the hæmorrhage increased, if we adopt the idea that the bleeding occurred into a cyst which had formed before the hæmorrhage took place.

Two other explanations might be offered. First, that the parenchymatous hæmorrhage produced the cyst; the circumscribed coagulum separating the interstitial tissue, and the lining of this space with endothelial cells developed from the connective tissue cells, and subsequent hæmorrhage from the interior of the cyst wall. Again, the hæmorrhagic cyst might have originated in a dilatation of one of the vessels of the pancreas, a varicose ectasia of a vessel.

In the second case it appears more than probable that hæmorrhage occurred by rupture of a vessel and extravasation of blood into the altered parenchyma of the gland, distending the entire capsule of the organ—in other words, a hæmatoma of the pancreas. In Parson's case the clinical history and the post-mortem appearances prove beyond all doubt that the fatal hæmorrhage took place into a preëxisting pancreatic cyst. The immediate cause of hæmorrhage in this case was undoubtedly due to inflammatory changes in the interior of the cyst after the first rupture, and to sudden diminution of intracystic pressure by the second rupture.

b. Diffuse Hæmorrhage.

Case 1. Reported by H. Hudson Rugg.[1] A man, aged forty-two years, had just recovered from an attack of acute articular rheumatism, when he was

[1] The Lancet, May, 1850.

attacked suddenly with a severe pain in the left lumbar region. He became collapsed almost instantly. This was followed by cold, clammy sweat and other symptoms of acute anæmia. He never rallied, and died within a few hours. On opening the abdomen after death a large quantity of recently extravasated blood was found between the pancreas and left kidney. A careful search for the source of hæmorrhage was made, when it was found that the blood had escaped through an opening of considerable size, which presented the appearance of an ulcer, on the anterior surface of the pancreas, which contained a blood-clot the size of a walnut. Sections through the pancreas showed a number of small excavations filled with blood, the size of a hazelnut and smaller, which looked like aneurismal dilatations.

Case 2. Reported by Oppolzer.[1] The patient suffered from severe pain in the epigastric region, followed by vomiting, which always aggravated the suffering. The vomited matter consisted of mucus and bile. The disease was attended by fever, very frequent pulse, cold extremities. The bowels were constipated. No blood was vomited, and the case was diagnosticated as perforating ulcer of the posterior wall of the stomach. On the third day after admission to the hospital he died. At the autopsy the stomach was found in a healthy condition, but around the pancreas and between the layers of the mesentery a copious effusion of blood was found. The pancreas was the source of hæmorrhage. This organ was enlarged to double its normal size, of dark red color, and on section, was found infiltrated with a blood-stained exudation between the acini.

Case 3. Reported by Hilty.[2] The patient was a mechanic, aged thirty; tall, stout, and muscular, but of intemperate habits. One evening he drank beer to excess, and on the following morning without any premonitory symptoms, he was seized suddenly with a painful tension of the abdomen, which gradually increased in intensity. He was sent to the hospital, where on examination, he was found in a collapsed condition. Extremities cold, forehead covered with a cold, clammy perspiration. All the symptoms indicated acute anæmia. On physical examination nothing abnormal was found, except that the upper part of the abdomen was distended and painful, especially to pressure. Diagnosis of poisoning or gastritis was made, and treatment adopted in accordance with this view. The patient never rallied, and died in the evening of the following day.

At the necropsy the omentum and mesentery were found loaded with fat. No abdominal effusion and no trace of peritonitis. The diaphragm was pushed upward as high as the fourth rib. In the connective tissue around the pancreas a copious effusion of blood was found. The pancreas was double its normal size, firm in structure, and of a dark violet color. On section the lobules were seen to be of a dark color, and the interlobular tissue infiltrated with blood: this infiltration was most copious in the head of the organ. The gland duct was normal, but the vein running along the lower border of the pancreas was

[1] Medizinische Neuigkeiten, April, 1859.

[2] Correspondenzblatt für Schweizer Aerzte, Nov. 15, 1877.

distended with blood-clots. No other pathological conditions were found which could explain the sudden death.

CASE 4. Described by Portal.[1] This is the first case of this kind on record. A merchant had suffered for two years from colicky pain in the abdomen, nausea, and diarrhœa; emaciation appeared early and continued progressively. Twenty days before his death fever made its appearance. The pancreas presented a violet color, was softened, and from its entire surface exuded a black offensive fluid. Stomach and duodenum showed evidences of inflammation at some points adjacent to the pancreas.

CASE 5. Reported by Haller and Klob.[2] Patient was a man, sixty-six years of age, who had died after a short illness. The pancreas was found almost completely detached, its only connection with the adjacent organs being a few strings of connective tissue. It was surrounded by a serous fluid. The stomach was perforated from without, the cells of the pancreas were disintegrated, granular, and changed into detritus, and the splenic vein was filled with a thrombus.

CASE 6. Reported by Kollman.[3] Female, suffering from stenosis of mitral valve and pleuritis on the left side. One afternoon, after having partaken of a liberal dinner, she had an attack of diarrhœa, but no vomiting. During the night she had a chill, and an anxious sensation with jactitations. In the morning of the following day she felt greatly improved, but soon after expired suddenly. At the autopsy there was found subperitoneal extravasation of blood at the pyloric end of the stomach. Mucous membrane of duodenum along the convex side was infiltrated with blood, but intact. Pancreas hyperæmic, and surrounded with an extravasation of blood, which was most marked in the retroperitoneal connective tissue, extending to the hilus of the spleen. The tail of the pancreas was more hyperæmic than the remaining portion of the gland, and was infiltrated with blood.

CASE 7. Gerhard's case, reported by Kollman.[4] The patient was a female, who, from the symptoms presented, was supposed to suffer from bronchial catarrh, emphysema, ascites, and anasarca. She was suddenly seized with collapse, and died in a few hours. At the necropsy the subperitoneal tissue of the duodenal peritoneum was found suffused with blood. Considerable hæmorrhage into pancreas, and the retroperitoneal space behind pancreas was distended with blood.

REMARKS.—A careful perusal of the above cases must satisfy the most casual observer that the hæmorrhage was produced by different causes, and constituted simply an expression of different pathological conditions. In the material presented, three distinct, primary, patho-

[1] Traité de l' apoplexie, Paris, 1811.

[2] Wiener Zeitschrift, N. F., 11, 37, 1859.

[3] Bayr. ärzt. Intelligenzbl., No. 39, 1881.

[4] Op.cit.

logical conditions will be recognized: 1. Disease of the blood-vessels of the pancreas; 2. Chronic parenchymatous degeneration of the gland: 3. Acute hæmorrhagic pancreatitis.

In Rugg's case the patient had just passed through the stages of acute articular rheumatism, and had not suffered from symptoms referable to organic disease of the pancreas, when he died suddenly from internal hæmorrhage, which was traced to the pancreas. The pancreas itself showed no other pathological changes, except circumscribed cavities filled with blood, which are referred to as resembling aneurismal sacs.

Case 3, reported by Hilty, is an illustration of the second class. Extensive fatty degeneration was found to exist in the tissues generally. Klob found interstitial hæmorrhage in the pancreas, in connection with chronic interstitial inflammation of the pancreas, and as a result of prolonged congestion of the portal vein.

Zenker reported three cases, which he observed in the course of one year, to the Naturforscher Verein at the Breslau meeting in 1875. In all, the amount of blood extravasated was slight. His observations on hæmorrhagic infiltration of the pancreas as a cause of sudden death, are of great importance to the medical and legal professions. Death from this cause takes place more frequently than is generally supposed.

The facts observed by Zenker were nearly the same in all cases. A corpulent subject died suddenly, or was found dead. Post-mortem examination revealed, as the only tangible pathological change, hæmorrhagic infiltration of the pancreas and neighboring connective tissue, and advanced fatty degeneration of the pancreas.

Further, there was found in two cases, bloody effusion in the duodenum, and in two, excessive engorgement of the semilunar ganglion. Zenker believes that paralysis of the heart, whether directly or indirectly caused, must be regarded as the immediate cause of death in these cases. Diffuse infiltration is more common than circumscribed, showing that the same cause exists throughout the entire gland. The bloody effusion is usually not limited to the capsule of the gland, but infiltrates the adjacent spaces, more especially the retroperitoneal connective tissue. The gland is softened, the anterior serous covering disorganized, and the extravasated blood escapes into the bursa omentalis. These conditions are

followed rapidly by death, so that even the peritoneum shows no secondary changes.

In the last class of cases, where the hæmorrhage occurs as a symptom of a peculiar and exceedingly malignant form of inflammation of the pancreas, we have reason to believe that the inflammation is due to the presence of a specific form of infection. Klebs believes that in these cases the corroding qualities of the pancreatic secretion may induce the destructive process. Reasoning from analogy, it is, however, probable that the immediate and essential cause is to be found in some form of microbic infection.

The last two cases illustrate that prolonged congestion of the abdominal organs, from obstruction to the return of venous blood, may act as an exciting cause in producing parenchymatous hæmorrhage into the pancreas altered by antecedent pathological conditions.

2. Symptoms and Diagnosis.

The premonitory symptoms which precede the hæmorrhage are referable to the particular kind of tissue changes in the pancreas which predispose to rupture of the blood-vessels. In all instances of pathological hæmorrhage we have the usual train of symptoms which point to the textural changes in the pancreas as the seat of the lesion. Loss of appetite, nausea, vomiting, epigastric pain, constipation, and debility are the most prominent symptoms in cases of degeneration of the pancreas. When the hæmorrhage takes place in the course of an infective, hæmorrhagic pancreatitis, we have a complexus of symptoms indicating the presence of an acute inflammation of the organ, usually attended by a rise in temperature. In some cases the hæmorrhage produces death so rapidly, and the symptoms which attend this occurrence are of such short duration, that it has been impossible to determine them by actual observation.

When the patient dies from loss of blood, the accident is announced by the well-marked symptoms indicative of external hæmorrhage: a sharp pain in the region of the pancreas, followed almost immediately by collapse, cold extremities, absence of pulse, cold, clammy perspiration, and a speedy death. If hæmorrhage takes place into a preëxisting cyst, the presence of which has been previously determined, the accident may be suspected if pain is suddenly increased, the tumor becomes larger and more tense, and more par-

ticularly if the patient's condition indicates a sudden increase of anæmia. Physical examination can be of value only if hæmorrhage occurs into a preëxisting cyst of considerable size, or if the effusion of blood is sufficiently copious to give rise to an appreciable swelling in the immediate vicinity of the pancreas.

3. Treatment.

The propriety of surgical treatment of pathological hæmorrhage of the pancreas can only be entertained when the accident takes place in consequence of circumscribed, benign, pathological conditions, which in themselves do not jeopardize the life of the patient, and which admit of measures for arresting the hæmorrhage by direct treatment. Operative interference should, therefore, be limited to the class of cases described under the head of hæmorrhagic cysts of the pancreas. In well-defined cases belonging to this group, it would be justifiable to resort to abdominal section as the only means of arresting fatal hæmorrhage, by direct ligation of the bleeding points, or by removing the localized portions of diseased tissue from which the hæmorrhage has taken place.

For instance, in case 1, partial excision of the pancreas in which the ectatic vessel had ruptured would have definitely arrested the hæmorrhage without interfering with the physiological function of the remaining portion of the gland. When profuse hæmorrhage takes place into a preëxisting cyst of the pancreas, further hæmorrhage can be effectually arrested by establishing an external pancreatic fistula of large size, plugging the interior of the cyst with iodoform cotton, and applying firm elastic compression of the abdomen with a rubber webbing bandage over the antiseptic dressing. If this procedure should fail to arrest the hæmorrhage, the abdominal incision should be enlarged, and an attempt made to extirpate the cyst, with or without resection of that portion of the pancreas from which the cyst has grown, according to the size or location of the cyst.

In diffuse hæmorrhage of the pancreas due to localized lesion, the same treatment is applicable as advised in the treatment of hæmorrhagic cysts of the pancreas.

XI. Cysts of the Pancreas.

For a general consideration of this part of the subject I refer to my paper on "The Surgical Treatment of Cysts of the Pancreas."[1] I refer to this subject again for the purpose of adding new cases, and to modify the statement then made concerning the etiology of these cysts. Since then the following additional cases have been reported:

Case 1. Dixon[2] reports an interesting case of cyst of the pancreas, which terminated in death from compression of the bile-duct by the cyst. The patient was a male, forty-two years of age, who during a period of three months had suffered from three attacks of what seemed to be cholelithiasis, before he came under the reporter's care. For the last ten days he became jaundiced. On examination a tumor was found in the region of the gall-bladder, about four inches in diameter, which fluctuated on palpation, and ascended and descended synchronously with the respiratory movements, and received the impulse from the underlying aorta. The tumor was punctured and four ounces of a yellowish-red fluid removed, which solidified on exposure to the air. Two days after the puncture the tumor was considerably larger than before. The patient's strength gradually failed, until he died, thirty-four days after the puncture. At the necropsy it was ascertained that the tumor was a cyst of the pancreas, with thick walls, and light yellow mucous contents. The cyst occupied the head and part of the body of the pancreas and communicated with the ductus pancreaticus. The tail of the pancreas also contained a small cyst. The large cyst compressed the ductus choledochus in such a manner as to render it entirely impermeable. It is evident that in this case a removal of the pressure by operative treatment might have restored the health of the patient, by removing the cause of obstruction to the natural outlet for the bile.

Case 2. Reported by Riedel.[3] A woman, forty-five years of age, had noticed for nine years a small tumor in the upper portion of the abdomen, which increased slowly in size until a year and a half before she was examined by Riedel. After this time growth was very rapid, so that a great deal of pain and distress was experienced from the size of the tumor. When she was examined, the abdomen was filled completely with a fluctuating tumor; the pelvis and the lateral regions of the abdomen were free. Laparotomy was performed August 27, 1884. The slightly adherent omentum was easily separated, the cyst was tapped, and about ten litres of a brownish fluid escaped. After evacuation of the cyst, the transverse colon could be seen immediately behind the symphysis pubis. The mesocolon had been separated with the omentum. The cyst was separated from the loose attachments with neigh-

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[1] American Journal of the Medical Sciences, July, 1885.

[2] Medical Record, March 15, 1884.

[3] Archiv für klinische Chirurgie, vol. xxxii. p. 994.

boring organs. Troublesome hæmorrhage only occurred from the depth of the wound near the vertebral column, where a ligature *en masse* was applied and several vessels tied; the cavity of the wound, the size of two fists, was dusted with iodoform. Death from peritonitis after ninety-six hours. At the necropsy a portion of healthy pancreatic tissue was found ligatured with catgut. The interior surface of the cyst showed, for the most part, a smooth surface without epithelium. At different points it presented prominences which contained glandular tissue.

Case 3. Reported by Salzer from Billroth's clinic.[1] Female, thirty-three years of age, not married; suffered from an attack of typhus fever when she was eighteen years old. On admission into the hospital she stated that during her convalescence she noticed a swelling the size of a goose egg in the middle of the abdomen above the umbilicus, which disappeared in a few weeks. Four years later the swelling reappeared in the same place; it was now the size of a fist, but little movable, and rendered the umbilical region prominent. The size of the tumor increased gradually, until four years ago it had attained the size of a fœtal head, and had descended below the umbilicus. A sensation of weight in the stomach, vomiting, pain in the abdomen, were the most prominent symptoms during the last fourteen days. Menstruation regular.

Before the operation a systematic and careful examination showed no disease in any other organ. Circumference of abdomen below the umbilicus, ninety centimeters. An unusually large vessel was detected in the abdominal wall in the left hypochondrium, which pulsated strongly, and over which, by auscultation, a bruit could be heard. Abdomen prominent, especially in the median line. On palpation the swelling was recognized as a round, smooth, fluctuating tumor, which was in direct contact with the anterior abdominal wall and could be moved slightly from side to side. Percussion dullness over the entire area of the tumor. Both lumbar regions resonant. Spleen and kidney dullness normal. A vaginal and rectal exploration showed that the cervix and uterus were pushed toward the right side, but movable. Behind the uterus a firm tumor could be felt. The diagnosis made at the time was unilocular cyst of the left ovary.

Laparotomy was performed June 5, 1885. Median incision exposed the omentum over the cyst, slightly adherent. An opening was made in the omentum with a blunt instrument, through which the cyst wall became visible. The hand introduced through this opening showed the existence of firm adhesions of the cyst wall to neighboring organs. After enlarging the external incision the gastro-colic ligament could be seen stretched over the cyst. The transverse colon lined the lower border of the cyst, and had descended behind the symphysis pubis. When this portion of the intestine was elevated, it was seen that the cyst belonged to the mesocolon. The separation of the cyst presented many difficulties, consequently its size was reduced by tapping, the opening was closed with pressure forceps, and enucleation commenced through a vertical slit in the gastro-colic ligament. Numerous ligatures *en masse* had to be applied to arrest troublesome hæmorrhage.

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[1] Zur Diagnostik der Pancreascyste, Prag, 1886.

On the left side of the cyst the same enlarged vessel was met with that had been felt externally; it was found so intimately adherent to the cyst wall that it could not be isolated; a double ligature was therefore made around it and the accompanying vein, and the vessel divided between the ligatures. To facilitate the deep dissection the incision was enlarged upward, and the cyst opened and emptied, the patient lying upon the side. The hand was introduced into the cyst, when it was found that the attached portion extended in an upward direction. The artery previously ligated had to be tied again higher up. In completing the tedious enucleation no pedicle was found. From the position, it could be ascertained that the base of the cyst was in the vicinity of the pancreas.

After careful arrest of hæmorrhage at the bottom of the wound, and the usual toilet of the peritoneum, the external wound was closed completely, no drainage being used. The patient, who had become considerably collapsed, was rallied by the administration of stimulants. In the evening, temperature 37.6° C., pulse 72, pain in abdomen, and nausea. Restless during the night. During the next few days the pulse became more frequent, with jaundice and diarrhœa, great restlessness and collapse, which terminated in death on the sixth day after the operation. At the autopsy extensive purulent peritonitis was found to have been the cause of death. In the transverse mesocolon a hole was found, through which a fist could be passed. Through this opening a cavity, the size of a fist, was entered, the walls of which were infiltrated with blood and pus. In the bottom of this cavity the exposed pancreas was seen, which appeared divided transversely behind the head. Along the margin of the pancreas the splenic artery and vein were found ligated, and a portion of both vessels excised. The middle portion of the pancreas was absent. A portion of the tail of the organ, five centimeters in length, remained. Spleen enlarged to twice its normal size, otherwise normal in structure. Remaining organs healthy. A microscopical examination of the cyst showed that its walls contained pancreatic tissue. Inner surface not lined with epithelial cells.

Case 4. Reported by Kramer, operation performed by Hahn.[1] Female, sixteen years of age, after an attack of vomiting and pain in the abdomen, noticed a gradual distention of the upper portion of the abdominal cavity. The size of the tumor and the area of dullness corresponding were about the same as in my case. The dullness appeared to be continous with the hepatic dullness. Echinococcus cyst of the liver was diagnosticated. Laparotomy was performed, and the omentum divided between the stomach and the transverse colon. About two litres of an albuminous fluid were removed by tapping. The cyst was stitched to the margin of the abdominal wound, incised, and drained. The patient recovered with an external pancreatic fistula, which continued to secrete pancreatic juice for four months.

Remarks.—The experiments made for the purpose of ascertaining the effect of complete and permanent obstruction of the pancreatic duct, as detailed in the first part of the paper, have demonstrated

[1] Centralblatt für Chirurgie, No. 2, 1885.

conclusively that obstruction is not the only, nor the most important element in the causation of a pancreatic cyst. That the ligated portion of the pancreas continued to secrete pancreatic juice was demonstrated by the experiments on external pancreatic fistulæ, and yet, of the many cases of ligation of the pancreas, in not a single instance was a cyst, or even an attempt at the formation of a cyst, observed. The only physical evidence of obstruction was apparent in a moderate and uniform dilatation of the duct behind the ligature. The most important etiological factor in cases of cysts of the pancreas must be sought in an arrest of absorption of the pancreatic juice, due either to a transformation of the pancreatic juice by the admixture of pathological products, into a substance which is incapable of being absorbed, or to a loss of function in this direction, of the vessels which perform this task.

The obstruction in the pancreatic duct may cause retention and accumulation of pathological products, but can never be the sole cause of retention of pancreatic juice in an otherwise healthy portion of the pancreas. In the cases where normal pancreatic tissue was found in the cyst walls, it was more than probable that the pathological condition which had caused the obstruction did not effect complete physiological detachment of the peripheral portion of the pancreas; in other words, the obstruction was not complete. In cases where complete physiological detachment has taken place, either by the application of a ligature, or complete obliteration of the duct by pathological conditions, parenchymatous degeneration and atrophy in the detached portion are such constant results, that the exceptions to this rule must indeed be few, if any.

To the diagnosis of pancreatic cysts nothing new has been added. The history of the case, the primary starting-point of the tumor in the epigastric region, its gradual and almost painless growth, are points which should be carefully considered in the differential diagnosis of abdominal cysts. The treatment by extirpation, as only recently practiced again by Riedel and Billroth, is not deserving of imitation,

The post-mortem examination in Billroth's case shows only too plainly the difficulties met with in identifying the tissues at such great depth, and the difficulty of avoiding unnecessary injury to important structures. Extirpation of the cyst would guard most effectually against the formation of a permanent pancreatic fistula,

but, on account of the deep location of the pancreas, the shortness or absence of a pedicle, and the many obstacles thrown in the way of the operator by adjacent organs, the procedure becomes one surrounded by innumerable difficulties and, in the present state of our science, of doubtful propriety.

The formation of an external pancreatic fistula in the treatment of cysts of the pancreas has been so uniformly successful that it should be invariably adopted in preference to excision. The latter operation should only be resorted to in cases where portions of the cyst wall have become the seat of malignant disease, and in cases where life is threatened by hæmorrhage into a cyst by the rupture of vessels lining the interior of the cyst, which cannot be controlled by simpler and less hazardous measures.

XII. Tumors of the Pancreas.

1. Hypertrophy.

Case 1. Störck[1] mentions a case of intestinal obstruction caused by hypertrophy of the pancreas. A man, forty-eight years of age, previously in good health, had felt a sensation of weight and distress after meals, for more than six months. The flatulency also caused distress, and was relieved at times by drinking large quantites of water. Bowels constipated. The symptoms of obstruction developed gradually, but finally became so severe that nothing was retained on the stomach. After obstruction had become complete, the patient became collapsed and died two days later. At the autopsy no signs of inflammation or effusion in the peritoneal cavity could be found. The head of the pancreas, which was enlarged to the size of an orange, had so completely compressed the duodenum that its lumen would only permit the passage of a goose quill. The pyloric portion of the stomach was enormously dilated, so that this pouch resembled a kind of lesser stomach. The pancreas was softer, more succulent, and fleshier than normal, but not at all indurated.

Remarks.—As no microscopical examination of the tumor was made, we are unable to classify this case, but considerable doubt must remain whether it was a case of tumor or simple hyperplasia of the gland. The age of the patient and the effect of the tumor upon the duodenum make it quite probable that it was not a case of hypertrophy, but rather one of carcinoma or sarcoma. The case illustrates the fact that tumors of the pancreas, when they occupy the head of the organ, are liable to produce intestinal obstruction by compression.

[1] Annus Medicus, 1836; Schmidt's Jahrbücher, Supp. Band, 1836, p. 161.

2. Sarcoma.

Of the malignant tumors of the pancreas, carcinoma is of much greater frequency than sarcoma. Only a very few cases of primary sarcoma of the pancreas are on record.

Case 2. Mayo[1] mentions a case of primary sarcoma of the pancreas, with secondary invasion of the stomach, that came under his care. The patient, a man aged thirty-five years, died after an obscure illness which lasted eight months, during which time it was impossible to locate the disease. He dated his illness back to a febrile attack, which left him in a debilitated condition; and from that time he was liable to dyspeptic symptoms, with variable appetite and undefined uneasiness in the epigastric region. A high degree of anæmia was a conspicuous symptom during life. Although the appetite remained good, and digestion did not appear to be very much impaired, emaciation progressed rapidly. On inspection all the internal parts were found extremely pale, and void of blood; the heart healthy, but nearly empty. The pylorus was thickened and firmer than usual, and had contracted adhesions to the pancreas. The pancreas was considerably enlarged and of nearly cartilaginous hardness, except in some spots, which were soft, with the appearance of medullary sarcoma. No other disease could be detected in any other part of the body.

Case 3. Lépine and Cornil[2] examined the body of a man, sixty-two years of age, who had been sick for eleven months, and had suffered from obstinate vomiting for seven months. The head of the pancreas was found very much enlarged; the remaining portion of it was normal. The small curvature of the stomach was adherent to the tumor, the pyloric orifice thickened and its lumen narrowed. The adhesions involved also the liver, diaphragm, and lower surface of the lung. White metastatic nodules were found in both kidneys. Under the microscope, sections of the tumor revealed a sarcomatous structure.

Remarks.—In the two cases related here, we have the principal types of the clinical behavior of sarcomatous tumors. In the first case the disease involved almost the entire organ, having given rise to extensive local destruction without metastasis; in the second case the disease was limited locally to the head of the pancreas, while it had extended early by contiguity to adjacent organs, and by metastasis to distant organs.

Friedreich[3] claims that at present we are acquainted with only one single reliable case of primary sarcoma of the pancreas. It is described by Paulick, and was found to be of the small-celled

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[1] Outlines of Human Pathology, p. 411.

[2] Contrib. à l'anatom. path. du pancréas, Gaz. Méd. de Paris, 1874, p. 624.

[3] Ziemssen's Cyclopædia, vol. viii. p. 614.

variety; it was taken from the body of a young man who had died of pulmonary and intestinal phthisis. It had not given rise to any noticeable symptoms during life.

3. Carcinoma.

It is claimed by some pathologists that primary cancer of the pancreas is an exceedingly rare affection, and that in the majority of cases where this organ is the seat of the lesion, it occurs as a secondary affection, having reached it by extension from an adjacent organ, especially from the pyloric extremity of the stomach. While this may be true in many cases, quite a number of specimens have been examined where the disease occurred here as a primary affection.

Suche[1] appears to have examined a specimen which affords a good illustration of primary cancer of the body of the pancreas. The middle of the gland was converted into a hard, irregular, nodulated mass the size of a fist, which rested directly upon the aorta which imparted to it pulsation during life. When cut into, the tumor grated under the knife, and the cut surfaces presented a laminated appearance. The substance of the tumor was traversed by numerous large veins; both extremities of the pancreas were healthy, and no secondary nodules could be found in any portion of the body.

A primary cancer of the pancreas is also described by Schupman[2], where the tumor had formed adhesions with the spleen, while the liver contained a number of metastatic deposits. The terminal extremity of the pancreatic duct contained a cylindrical calculus with a number of arborescent projections, which corresponded to the contributory ducts. In another case, reported by Récamier,[3] the cancerous tumor, which involved the tail of the pancreas, was connected with the left kidney and compressed the ureter. The right half of the pancreas was healthy, the diseased portion gray, hard, and lardaceous. The pelvis of the left kidney, in consequence of the compression of the ureter, was hydronephrotic. The remaining organs were healthy.

Bright, in 1832, reported a number of cases of primary carcinoma of the pancreas, with a special view of illustrating the effect

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[1] De Scirrho pancreat. nonnula, Dissert. Berol., 1834.

[2] Hufeland's Journal, 1841.

[3] Revue Médical, 1830.

which disease of this organ would have upon the digestion of fat. In three out of eight cases he noticed fatty diarrhœa, and he was inclined to the belief that this symptom, when present, is almost pathognomonic of the existence of disease of the pancreas.[1]

In all cases the fatty diarrhœa was associated with jaundice. The following post-mortem account[2] leaves no doubt that the disease was primarily limited to the pancreas: "The cause of the pressure on the bile-ducts was immediately obvious; for, on placing the hand near the pylorus, a hard lump, of the size of a common egg, was easily felt, and was soon discovered to be the head of the pancreas itself, and not the glands surrounding that part, forming a yellow mass like the boiled udder of a cow, almost cartilaginous in hardness. Its texture was uniformly hard and unyielding, and the whole pancreas partook of the same, but in a less degree. The head of the pancreas was firmly and inseparably glued to the duodenum, and the hardness very nearly surrounded the viscus."

As undoubted instances of primary cancer of the pancreas, we must mention the following cases:

Albers. Med. Correspbl. rhein u. westf. Ärzte, No. 8, 1843.
Bowditch. Boston Medical and Surgical Journal, July, 1872.
Davidsohn. Ueber Krebs der Bauchspeicheldrürse, Dissert., Berlin, 1872.
Frerichs. Klin. d. Leberkrankheiten, vol. i. pp. 146 and 153.
Friedreich. Diseases of the Pancreas. Ziems. Cyclop., vol. viii, p. 608.
Gross. Philadelphia Medical Times, vol. ii. June, 1872.
Haldauer. Assoc. Medical Journal, May, 1854.
Luithlen. Mem. a. d. ärtzl. Praxis. 1872, vol. xvii, p. 309.
Muehry. Casper's Wochenschrift. No. 10, 1835.
Roberts. British Medical Journal, September, 1865.
Wagner. Archiv. der Heilkunde. vol. ii. p. 285.
Webb. Philadelphia Medical Times, vol. ii. December, 1871.
Williams. Medical Times and Gazette, August, 1852.

According to Da Costa,[3] cancer of the pancreas is more frequent in the male than in the female, and in preference attacks people more than forty years of age. It usually appears as a firm tumor or scirrhus, with a well-developed connective tissue reticulum. Other varieties of carcinoma have been described. Thus, Wagner

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[1] Cases and Observations Connected with Disease of the Pancreas, Medico-Chirurgical Transactions, vol. xviii. p. 1.

[2] Ibid, p. 17.

[3] North Am. Med. Chir. Review, September, 1858.

observed a cylindroma, and Lücke and Klebs have each met with the colloid variety. The primary starting-point is usually in the head of the organ, whence it extends in all directions. By extension within, it successively invades the body and tail of the organ, until the whole gland is involved, when it forms a nodulated spherical tumor.

The extension of the growth in an opposite direction soon reaches the duodenum, where it produces a narrowing or complete stenosis of that portion of the intestinal canal. A case of this kind is related by Hœlscher, where the duodenum was constricted to such an extent that it was entirely impermeable, and the patient suffered for several days from symptoms of intestinal obstruction. While cancer of the stomach is liable to extend to the pancreas, the reverse is not frequently observed. When the carcinoma develops primarily in the pancreatic ducts, it belongs to the variety called cylindroma. The lymphatic glands in the vicinity of the pancreas are invariably affected during the later stages of the disease.

4. Symptoms and Diagnosis.

Stearrhœa is an important but not infallible symptom of cancer of the pancreas. It is attributed to an absence of the pancreatic juice in the intestinal canal, caused either by obstruction in the duct or suspension of the physiological function of the organ by the neoplastic infiltration. Epigastric pain is an early and important symptom, and is the result of compression of the cœliac plexus by the tumor. The pain often assumes a neuralgic character, and is usually not aggravated after taking food. Vomiting is a frequent symptom, and the matter ejected is generally a watery fluid, sometimes stained with bile. Constipation is an almost constant symptom.

Progressive emaciation and anæmia attend malignant disease in any locality, but are unusually well marked in cancer of the pancreas. When the disease extends toward the duodenum, jaundice occurs from stenosis of the bile-ducts by compression or direct invasion by the neoplasm. Bruen has called attention to some forty cases of jaundice due to primary carcinoma of the head of the pancreas, lately reported by another observer, from which it is demonstrated that jaundice is an invariable symptom of primary scirrhus of the head of the pancreas, while it is uncommon when the disease is secondary, or affects the body or tail of the organ.

The most reliable evidence is the appearance of a tumor in the epigastrium, behind the stomach. The difficulty of examining the pancreas during health by palpation is appreciated when a physical examination is to be relied upon in locating tumors in this locality. The normal pancreas can be felt only under the most favorable conditions through a thin and relaxed abdominal wall, but in determining its relative size this method of examination affords but little reliable information. A cancer of the pancreas, when it can be felt by palpation, appears in the epigastrium as a hard, immovable or only slightly movable tumor, which is evidently deeply seated in the abdominal cavity.

Under favorable conditions the connections of such a tumor with the pancreas can sometimes be demonstrated during life, but a positive diagnosis becomes impossible when, as in most of the cases hitherto recorded, it constitutes merely a part of a general tumefaction of the abdomen. As the tumor is in such close proximity to the abdominal aorta, the pulsations of this vessel are imparted to the tumor, and a bruit may even be heard over the compressed vessel; but, in contradistinction to aneurism, the pulsation is felt in only one direction, and the bruit disappears when the patient is placed in the knee-elbow position, as the tumor is lifted from the vessel by the force of gravitation.

That the tumor cannot be always felt is evident from the statement made by Da Costa that he recognized it in only thirteen out of the one hundred and thirty-seven cases he reported; and Bigsby, in an analysis of fifteen cases, alludes to its being recognized in only four.

From what has been said it will be seen how uncertain the symptoms are in the diagnosis of cancer of the pancreas. A satisfactory conclusion can be reached only after a careful consideration of the history of the case combined with a systematic elucidation of all the symptoms presented, and more particularly by resorting to the advantages to be derived from a systematic and careful study by exclusion.

5. Treatment.

A positive diagnosis of malignant disease of the pancreas is only possible after the tumor has attained sufficient size to be recognizable by palpation, consequently too late for a radical extirpation.

When the disease has advanced to this stage it has already involved the greater portion of the gland and, as a rule, has invaded important adjacent organs. Another important element in the surgical treatment of cancer of the pancreas consists in the fact that the disease, as a rule, develops primarily in the head of the organ, a location which, in itself, precludes the propriety of an operation.

The most favorable conditions for extirpation are presented if the disease is primarily located in the tail of the pancreas, and has not passed beyond the limits of the capsule of the gland. In such a case, excision of the splenic extremity of the pancreas would offer a fair prospect for a permanent result without endangering, as a remote consequence, the process of digestion, as a sufficient amount of secreting structure would remain in connection with the intestine to maintain pancreatic digestion.

Billroth, in two instances, made a partial resection of the pancreas in removing carcinomatous tumors of adjacent organs. In one case he removed a portion of the head of the pancreas with a cancer of the pylorus, and in another case he removed the tail of the pancreas with a sarcomatous spleen. Both patients recovered from the immediate effects of the operation. In the case of partial excision of the head of the pancreas it is to be assumed that the duct was not injured, that the organ continued to secrete, and that the pancreatic juice was discharged into the duodenum through the uninjured duct. In operating upon the head of the pancreas for malignant disease which has extended to it from an adjacent organ, it is essential to preserve the continuity of the duct, so as to prevent physiological detachment of the remaining portion of the gland, an accident which would be followed by degeneration and complete atrophy, consequently suspension of pancreatic digestion.

If an operation is performed for cancer of an adjacent organ, and the disease has extended to the splenic extremity of the gland, the operation should not be completed without removing a sufficient portion of the pancreas to guard against a local recurrence of the disease in this organ. As in cases of partial excision of the pancreas for other lesions, the pancreas should be ligated before it is divided, so as to prevent troublesome hæmorrhage, and at the same time guard against extravasation of pancreatic juice into the peritoneal cavity.

XIII. Tuberculosis of the Pancreas.

Primary tuberculosis of the pancreas is an exceedingly rare affection; indeed, some pathologists, among them Louis and Lebert, doubt its primary origin in this organ. Cruveilhier only mentions tubercular degeneration of the lymphatic glands upon the surface of the pancreas. In diffuse miliary tuberculosis of the abdominal organs Klebs could find no nodules in the substance of the pancreas on microscopical examination. But in such a condition the gland is often found in a state of parenchymatous degeneration, which has been incorrectly interpreted by Ancelet, as the first stage of tuberculosis.

When the lymphatic glands around the pancreas have undergone cheesy degeneration we sometimes find similar deposits in the pancreas, which, however, may be cheesy lymphatic glands in the substance of the pancreas itself. Hartmann mentions a case where the pancreas had disappeared completely and its place was occupied by a cheesy mass. Although the pancreas is not disposed to tuberculosis, we have reliable information that in a number of cases this gland was the primary seat of the process.

CASE 1. Reported by Aran.[1] The patient was a woman, twenty-five years of age, who died of a lingering disease. She had been sick for a year, during which time she felt exceedingly weak, had frequent attacks of vomiting. and the skin became deeply bronzed, in some places almost black. The pain. which was severe at times, was referred to the epigastrium. The necropsy showed a tubercular deposit in the tail of the pancreas, the size of a hen's egg, surrounded by a zone of miliary deposits in the substance of the gland. Miliary tubercles were also found in the spleen.

CASE 2. Mayo [2] describes a case where we have reason to believe that the process commenced primarily in the pancreas. The patient was an inmate of Middlesex Hospital, and was under the care of Dr. Wilson. He was thirty-eight years of age and had been ill for sixteen weeks; during the last seven weeks he was confined to his bed. The first symptoms were pain in the abdomen extending along the right hypochondrium to the spine. Twenty-eight days before death he became jaundiced, stools white, urine high colored; for some time he could lie on the right side only, and was often obliged to sit upright to draw breath. A large abdominal tumor had been felt immediately above the umbilicus some time before death, and the right arm and side of the neck had become œdematous.

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[1] Archives générales de Médecine. 1846.

[2] Outlines of Human Pathology, p. 410.

Autopsy: Serous effusion into the right pleural cavity. The gall-bladder was distended to a great size so that it contained eight ounces of fluid. The distention arose from an enlargement of the pancreas, the head of which formed an irregular sphere four inches in diameter, which had compressed the gall-duct; the rest of the gland was also enlarged. In parts it presented its natural texture and color, at other parts it was infiltrated with tubercular matter, which at two or three points had softened and formed thick pus. A few lymphatic glands, the thymus gland, and kidneys, appeared to be secondarily involved.

REMARKS.—Although in both of these cases the symptoms during life pointed to disease of the pancreas, a sufficiently positive diagnosis to warrant a laparotomy could only have been made after a palpable tumor appeared, and after this time the disease had already passed beyond reach, by the appearance of miliary deposits in other organs, an occurrence which would preclude the justifiability of any operative interference. Should abdominal section be performed in a case of tubercular peritonitis, and should such a condition in the pancreas be found as in Aran's case, it would be proper to extirpate the terminal end of the pancreas inclusive of the tubercular abscess.

In Wilson's case the tubercular deposit in the pancreas gave rise to a large abdominal tumor, due partly to the distended gall-bladder, and as such a condition might present itself to the surgeon, in these days of diagnostitial laparotomy, it might be advisable, and to the advantage of the patient, to establish an external pancreatic fistula instead of closing the wound. Such a course would enable the surgeon to remove the cheesy material, disinfect the abscess cavity, and to treat its interior with iodoform, all of which, done under antiseptic precautions, would tend to modify favorably the local process.

The removal of compression of the bile-duct by the same procedure would also tend to reëstablish the interrupted communication between the bile-ducts and the duodenum by removing the cause of the stenosis.

XIV. Lipomatosis of the Pancreas.

Lipomatosis, or fatty infiltration of the pancreas, is a pathological condition of this organ which is characterized by a transformation of the interacinous connective tissue into fat, in contradistinction to fatty degeneration of the parenchyma cells, which sometimes occurs as an independent affection. In cases of fatty infiltration the

shape and size of the pancreas may remain normal, but the secreting structures themselves may have completely disappeared by pressure-atrophy. This disease is of little interest to the surgeon, except that it may serve as a predisposing cause of interstitial hæmorrhage, in which connection it has already received mention; it is here again alluded to as a separate affection, to demonstrate that gradual atrophy of the pancreas, even to the extent of complete disappearance of the glandular structures, may occur without causing serious impairment of the digestion.

Rokitansky[1] has found this condition of the pancreas generally as a part and parcel of a general obesity, especially in intemperate persons, together with fatty liver, heart, and omentum. In the three cases of pancreatic apoplexy described by Zenker, the fatty infiltration of the pancreas was only one of the many evidences of a diffuse malnutrition of the tissues. In some of these cases the patients exhibited no symptoms during life indicating the absence of the pancreatic secretion, and yet on making the post-mortem examinations, complete destruction of the glandular structure was found.

Litten[2] has reported three cases of complete atrophy of the pancreas in which, during life, no symptom of pancreatic disease, such as fatty stools, salivation, lipuria, bronzed skin, cœliac neuralgia, etc., was observed. In two cases the atrophy was due to pressure, and in one instance it was caused by primary cancer of the pancreas.

In other cases the suspension of the pancreatic function by fatty degeneration of the organ produces well-marked symptoms during life, and may even result in death. Such a case is reported by Lépine and Cornil.[3] The patient was a drunkard, fifty-seven years of age. For six months he had been ailing with indigestion, marked loss of weight, diarrhœa alternating with constipation, no fever, no vomiting. For two months his body was covered with an eruption, and his feet became œdematous. At the autopsy the pancreas was found normal in size and shape, but the parenchyma of the gland had entirely disappeared, and its place was occupied by adipose tissue. The pancreatic ducts were filled with a viscid

[1] Lehrbuch der path. Anat., vol. iii., pp. 313 and 369.

[2] Charité Annalen, 1881.

[3] Gazette Médicale de Paris, p. 624.

whitish fluid and small concretions. No other cause of death could be found in any of the remaining organs. Clinical observation appears to confirm the results obtained by experiments on animals, that in some instances complete gradual atrophy of the pancreas is compatible with normal digestion, while, in other cases, the suspension of the pancreatic secretion is followed by serious disturbance of digestion, marasmus, and death from inanition.

The only plausible explanation of the different effects of the same cause can be found in the supposition that in some individuals, the compensating function of vicarious organs maintains normal digestion, while in others no such compensating action is established.

XV. Lithiasis of Pancreatic Ducts.

Concretions of carbonate and phosphate of lime are frequently found in the pancreatic ducts. They are usually multiple, small, whitish, smooth, or of rough and irregular shape. Calculi in this locality have been found which measured more than an inch in diameter. In Schupman's case, the calculus weighed two hundred grains and measured one and a half Paris inches in length, and from five to six Paris lines in diameter; having a crystalline surface, with processes running into smaller ducts. It was found in the left extremity of Wirsung's duct.

Sometimes concretions of calcium phosphate and carbonate exist in cases of incrustation of the mucous lining of the ducts. According to Collard de Martigny, the calculous concretion is sometimes composed of phosphate of lime alone. The calculi in this locality are usually solid formations, of fine granular structure with somewhat rough surfaces, and are very often covered with sharp points of projection. In some specimens the stone presents numerous branches which correspond to smaller pancreatic ducts. The irritation incident to the presence of a calculus in the pancreatic duct is followed by consecutive pathological changes in the duct and glandular tissue of the organ itself. The substance of the organ in the immediate vicinity of the stone becomes the seat of interstitial inflammation, followed by atrophy and sclerosis; the cicatricial tissue produced by this change causes contraction, an occurrence which may still further aggravate the obstruction.

In some instances this inflammatory process does not remain localized, but extends over the entire gland, as in the cases observed by Engel, Elliotson, and Curnow. In some cases the concretion gives rise to suppuration, as in Portal's case. His patient had died suddenly with symptoms of aneurism of the aorta, and at the autopsy an abscess was found in the head of the pancreas, which contained a number of biliary and pancreatic calculi. In Fauconneau-Dufrèsne's case, as quoted by Ancelet, the left half of the pancreas contained a number of abscesses, one of which had perforated into the stomach. The pus contained numerous concretions varying in size from a pin's head to that of a bean. Salmade observed a case of lithiasis complicated with abscess of the pancreas, where the swelling compressed the underlying aorta to such an extent that death was produced by the rupturing of a vessel from over-distention on the proximal side of the obstruction.

Mr. Norman Moore[1] presented to the Pathological Society of London the pancreas of a man, aged forty-three years, who died in St. Bartholomew's Hospital of an attack of pleurisy following gouty symptoms. The main duct of the organ was dilated and contained a calculus of irregular shape, around which was a large abscess in the head of the organ. This abscess pressed upon the orifice of the bile-duct sufficiently to produce great distention of the gall-bladder.

A number of cases of cysts of the pancreas have been reported in connection with a calculus in the duct on the proximal side of the cyst, and in which the dilatation of the duct was attributed to obstruction due to the presence of the foreign body in the duct. Complete stenosis of the pancreatic duct, due to intrinsic or extrinsic causes, is always followed by parenchymatous degeneration of the glandular tissue on the peripheral side of the seat of obstruction, which necessarily arrests the physiological function in that portion of the organ; hence we are unable to explain the retention of the secretion from this cause, unless impaction of the calculus takes place suddenly.

Again, assuming this to be the case, we know that healthy pancreatic tissue will remove its own secretion by absorption in case of sudden stenosis or obstruction of the duct. We are, therefore, forced to attribute the occurrence of a pancreatic cyst in the course of

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[1] The Lancet, Jan. 12, 1884.

gradual or sudden obstruction of the ducts by a calculus, or cicatricial or malignant stenosis, to parenchymatous changes in the peripheral portion of the gland rather than to the obstruction. This argument, of course, applies only to the so-called retention cyst. Simple, uncomplicated obstruction of the duct may give rise to accumulation of pathological products which are under no circumstances amenable to removal by absorption.

The former assertion is well illustrated by the specimen referred to above, which Mr. Norman Moore[1] exhibited before the Pathological Society of London, which showed great dilatation of the common pancreatic duct throughout its entire length. Near the orifice the duct was obstructed by a small calculus of irregular shape. The whole gland was hard and to the naked eye showed a condition of advanced connective tissue hyperplasia. The papilla in the duodenum was enlarged and the hardened tissue of the pancreas constricted the bile-duct so as to cause complete obstruction. The liver showed secondary changes due to the stasis of bile. A microscopical examination of the specimen showed it to be a case of genuine cirrhosis of the pancreas, only a small number of acini remaining in healthy condition. In this case, the cirrhotic change in the organ was undoubtedly produced in the same manner as practiced in the experiments on animals, by constriction of the duct; the first link in the chain of pathological changes being the mechanical obstruction of the duct by the calculus.

1. Symptoms and Diagnosis.

A positive diagnosis of pancreatic lithiasis during life is impossible. Calculi and concretions have been found at post-mortem examinations of persons who, during life, did not suffer from any symptoms indicating the existence of such conditions. Pain, fatty stools, hæmatemesis, diabetes, are symptoms sometimes associated with this lesion of the pancreas, but when present they point rather to the existence of a consecutive lesion of the substance of the gland produced by the calculus, than to the presence of the calculus itself. If the calculus be arrested at the outlet of Wirsung's duct, it may, at the same time, obstruct the outlet of the bile by compressing the ductus choledochus, and so cause jaundice. But the same effect

[1] Op. cit.

can also be produced by cirrhosis of the head of the pancreas, with or without the presence of a calculus in the pancreatic duct.

Mr. Morris claims that he has seen cases of pancreatic stone colic, but in such cases it would be impossible to differentiate between the passage of a biliary and a pancreatic calculus along their respective ducts, as a biliary calculus may obstruct the common pancreatic duct and *vice versa.*

2. Treatment.

As the diagnosis of a calculus of the pancreas, *intra-vitam*, is impossible, the surgical treatment must be limited to the management of some of its consecutive lesions—cysts, abscess, and retention of bile.

The treatment of cystic disease and abscess of the pancreas has been considered under their respective headings, and I will only add that when these conditions have been caused by an impacted calculus, an effort should be made to recognize the primary cause and, if possible, to remove it. As the surgical treatment of retention of bile due to the mechanical obstruction of the biliary passages is now receiving much attention on the part of surgeons, it is well, in this connection, to call attention to impaction of a pancreatic calculus in the duodenal portion of the pancreatic duct, as an occasional cause of obstinate jaundice.

If, in a case of this kind, abdominal section should reveal the true nature of the obstruction, an effort should be made at the time to force the calculus into the duodenum by taxis, and if this cannot be accomplished, the propriety of cutting for the stone should be carefully considered. As an impacted calculus in this locality not only endangers the life of the patient by cholæmia, but may also destroy life suddenly by perforation into the peritoneal cavity, it would be not only justifiable but good treatment to remove it after a positive diagnosis has been made by means of diagnostitial laparotomy. The greatest danger attending such a procedure would be extravasation of bile into the peritoneal cavity. This accident should be guarded against by removing the retained bile by aspiration of the dilated bile-ducts, as a preliminary measure. After extraction of the stone the incision in the duct should be accurately closed with fine silk sutures. The secretion of bile and pancreatic juice

should be reduced to a minimum after the operation by keeping the digestive organs in a condition of absolute physiological rest during the time required for the healing of the visceral wound.

XVI. Conclusions.

1. Restoration of the continuity of the pancreatic duct does not take place after complete section of the pancreas.

2. Complete extirpation of the pancreas is invariably followed by death, produced either by the traumatism or by gangrene of the duodenum.

3. Partial excision of the pancreas for injury or disease is a feasible and justifiable surgical procedure.

4. Complete obstruction of the pancreatic duct, uncomplicated by pathological conditions of the parenchyma of the organ, never results in the formation of a cyst.

5. In simple obstruction of the pancreatic duct, the pancreatic juice is removed by absorption.

6. Gradual atrophy of the pancreas from nutritive or degenerative changes of the secreting structure is not incompatible with health.

7. Physiological detachment of any portion of the pancreas is invariably followed by progressive degeneration and atrophy of the glandular tissue.

8. Extravasation of fresh normal pancreatic juice into the peritoneal cavity does not produce peritonitis, but the juice is promptly removed by absorption.

9. Crushed or lacerated pancreatic tissue is removed by absorption, provided the site of operation remains aseptic.

10. Complete division of the pancreas by elastic constriction is never followed by restoration of interrupted anatomical continuities.

11. Limited detachment of the mesentery from the duodenum, as required in operations upon the pancreas, is not followed by gangrene of the bowel.

12. In all operations upon the head of the pancreas, the physiological connection of the peripheral portion of the gland should be maintained by preserving the integrity of the main pancreatic duct.

13. Partial excision of the splenic portion of the pancreas is indicated in cases of circumscribed abscess and malignant tumors, in all cases where the pathological product can be removed completely without danger of compromising pancreatic digestion or inflicting additional injury upon important adjacent organs.

14. Ligation of the pancreas at the point or points of section should precede extirpation as a prophylactic measure against troublesome hæmorrhage and extravasation of pancreatic juice into the peritoneal cavity.

15. The formation of an external pancreatic fistula by abdominal section is indicated in the treatment of cysts, abscesses, gangrene, and hæmorrhage of the pancreas due to local causes.

16. Abdominal section and lumbar drainage are indicated in cases of abscess or gangrene of the pancreas where it is found impossible to establish an anterior abdominal fistula.

17. Through drainage is indicated in cases of abscess and gangrene of the pancreas, with diffuse burrowing of pus in the retroperitoneal space.

18. Removal of an impacted pancreatic calculus in the duodenal extremity of the duct of Wirsung, by taxis, or incision and extraction, should be practiced in all cases where the common bile-duct is compressed or obstructed by the calculus, and where death is threatened by cholæmia.

19. In such cases the principal source of danger, extravasation of bile into the peritoneal cavity, should be avoided by preliminary aspiration of the dilated bile-ducts, accurate closure of the visceral wound with fine silk sutures, and absolute physiological rest of the organs of digestion during the time required for the healing of the visceral wound.

AN EXPERIMENTAL CONTRIBUTION TO INTESTINAL SURGERY WITH SPECIAL REFERENCE TO THE TREATMENT OF INTESTINAL OBSTRUCTION.[1]

The most important, and, at the same time, the most popular topic for discussion among surgeons of the present day is intestinal surgery. The current medical literature is teeming with reports of cases, and at the meetings of almost every medical and surgical society, large or small, this subject comes up for discussion and occupies a liberal space and conspicuous place in their printed transactions. The unusual activity which has been manifested in all parts of the civilized world in the development of this, one of the most modern and aggressive departments of abdominal surgery, is sufficient evidence that the subject is comparatively new, and as yet imperfectly understood. A study of the literature of intestinal surgery must convince every unprejudiced mind that here, as in many other difficult problems in surgery, the positive knowledge which we have acquired rests almost exclusively on the results obtained by experimental research. Gunshot wounds of the abdominal cavity have been made the object of careful and patient experimentation by a number of enthusiastic surgeons, and the results obtained have laid the foundation for a rational method of treatment of these injuries, which has been eagerly accepted by all modern aggressive and progressive surgeons. The practical results which have been obtained thus far in the hands of a number of surgeons have been the means of saving a number of lives, which by the old conservative method of treatment would have been doomed to inevitable death from hæmorrhage or septic peritonitis. The numerous valuable practical suggestions for treatment of gunshot injuries of the intestines are the direct outcome of experiments on animals, and this, as well as

[1] Read in the Surgical Section of the Ninth International Medical Congress, Washington, September 5, 1887.

the remarkable recoveries following gunshot wounds of the abdomen treated by laparotomy, have so firmly convinced the profession of the necessity of resorting to operative measures in such cases, that few surgeons could be found at the present day who would be willing to trust to conservative treatment any case where positive, or only probable, evidences pointed towards the existence of a visceral injury of any portion of the intestine.

While a decided advance has been made in the treatment of injuries of the intestinal tract, the operative treatment of intestinal obstruction still constitutes one of the darkest and most unsatisfactory chapters in the wide domain of intestinal surgery. The obscurity and uncertainty which cling to this subject are due to the difficulties which often surround an accurate diagnosis. At the same time we have every reason to believe that the appalling mortality which has so far attended the surgical treatment of intestinal obstruction is mainly due to late operations, and not infrequently to a faulty technique in the removal of the cause of the obstruction, and in the restoration of the continuity of the intestinal canal. An accurate anatomical or pathological diagnosis in such cases during life is often difficult, if not impossible, and when, as a *dernier ressort*, laparotomy is performed, and the surgeon is confronted by an unexpected condition of things, he is often in doubt as to what course to pursue, and frequently ends the operation by establishing an artificial anus. No one who has been forced to resort to this measure has left his patient with a feeling of satisfaction, as he must have been sadly impressed with the fact, that, at best, he has only been instrumental in relieving the urgent symptoms of the obstruction, while he has failed to remove its cause, and consequently also in restoring the continuity of the intestinal canal. A patient with an artificial anus is indeed an object of commiseration, as experience has sufficiently demonstrated how difficult it is in many instances to close the abnormal outlet, even after the cause of obstruction is subsequently removed or corrected spontaneously, without exposing him a second time to the risks of life incident to another abdominal section. If the causes which have led to the obstruction are of a permanent character, all attempts at closing the fistulous opening will, of course, prove worse than useless, and the patient is condemned to suffer from this loathsome condition the balance of his or her lifetime, without a hope of ultimate relief. I believe I can safely make the statement

without fear of contradiction that most of these unfortunate patients would prefer death itself to such a life of misery. The ideal of an operation for intestinal obstruction embraces the fulfillment of two principal indications:

1. The removal or rendering harmless of the cause of obstruction.

2. The immediate restoration of the continuity of the intestinal canal.

To meet the first indication the cause of obstruction must be found, its nature determined, and whenever advisable or practicable, it is removed, a step in the operation which may be very easy, or may demand a most formidable and serious undertaking, more especially in cases where the pathological conditions which have given rise to the obstruction are of such a nature as to constitute in themselves an imminent or remote source of danger, as, for instance, malignant disease or gangrene of the bowel from constriction. In all cases of inoperable conditions the cause of obstruction is rendered harmless as far as obstruction is concerned by establishing an anastomosis between the bowel above and below the obstruction by an operation which will be described further on.

Immediate restoration of the continuity of the intestinal canal should be secured in the operative treatment of all cases of intestinal obstruction, with the exception of inoperable cases of carcinoma of the rectum, but is most urgently indicated in cases of obstruction in the upper portion of the small intestines and the colon, as the formation of an artificial anus in the former locality would prove a direct source of danger from marasmus, by excluding too large a surface for intestinal digestion and absorption, while in the latter situation the cure of a fæcal fistula only too often proves an opprobrium of surgery. A careful perusal of the literature on the treatment of intestinal obstruction proves only too plainly the imperfection of this branch of surgery. The rules laid down in our text-books are often given with so much hesitation that it becomes impossible to apply them in practice. Opinions are so widely at variance that every surgeon finally acts upon the impulse of the moment and adopts a method which he deems appropriate for his case. It can be said that no uniformity of action exists, consequently the statistics which have been produced so far are of but little value from a practical standpoint. A rational and successful surgical

treatment of intestinal obstruction, like other abdominal operations, can only be established upon a basis founded upon the results obtained by experimental investigation. In view of this fact it is astonishing that so little has been accomplished in this direction. I am convinced that accurate work of this kind will render essential information in the diagnosis of the obscure causes of obstruction, and will point out more clearly the indications for operative interference, while improved methods of operation will have to be studied exclusively in this manner.

During the last eighteen months I have made one hundred and fifty operations on animals for the purpose of studying the effects of the principal varieties of intestinal obstruction, which were produced artificially; at the same time I have attempted to establish a number of new operations for the relief of certain forms of intestinal obstruction where it is impossible or inadvisable to remove the local conditions which gave rise to the obstruction. One of the greatest dangers in all operations for intestinal obstruction is the length of time required to perform the ordinary operations; hence it has been my object to simplify the operations, and thus by shortening the time diminish the danger from shock. All patients requiring an operation for intestinal obstruction are invariably in a condition not well adapted for prolonged operations, which necessitate the opening of the peritoneal cavity and exposure of its contents to the cooling influences of the atmospheric air. An operation which can be completed in twenty minutes must certainly prove less disastrous to the patient than one requiring from one to two hours. A prolonged operation on the intestines is attended by two great risks: 1. Immediate, due to shock. 2. Remote, prolonged exposure to infection. Both of these dangers are diminished in proportion to the shortening of the time consumed in the operation, which is made possible by resorting to simpler measures, provided they are equally safe and efficient.

General Remarks on Experiments.

With few exceptions the experiments detailed in this paper were made at the Milwaukee County Hospital, located at Wauwatosa, six miles from Milwaukee; and here I desire to return my thanks to Dr. M. E. Connel, superintendent of the hospital, and his assistants, as well as to Dr. William Mackie, of Milwaukee, for

valuable services rendered in my experimental work. As the main object of these experiments was not to show favorable statistics, but more for the purpose of studying the effect of different forms of intestinal obstruction and to establish new principles of treatment, the animals were not submitted to any special treatment before or after the operation; the diet was not restricted and no internal medicines were given. I pursued this course in order to bring the intestinal canal in the most unfavorable conditions for operative interference, so as to expose the operations to the severest test. Ether was used exclusively as an anæsthetic. The abdomen was shaved, thoroughly washed with soap and warm water, and disinfected with a 1-1000 solution of corrosive sublimate or a two and a half per cent. solution of carbolic acid. For the sponges the same solution of carbolic acid or a weaker solution of corrosive sublimate was used. The abdomen was covered by several layers of aseptic gauze, with a slit in the centre.

Whenever division or incision of the bowel was made, fæcal extravasation was guarded against by compressing the bowel on each side by compressors made for this special purpose, or by constriction with an elastic rubber band. Experience showed that the latter method was preferable, as it proved less injurious to the tissues of the bowel, and afforded greater security against extravasation, while at the same time it proved less disastrous to the circulation between the points of compression. The rubber bands for this purpose should be about an eighth of an inch in width, rendered properly aseptic by prolonged immersion in a five per cent. solution of carbolic acid, and can be readily applied by perforating the mesentery with an ordinary hæmostatic forceps at a point not supplied with visible blood vessels, and tied in a loop with sufficient firmness to obstruct the lumen of the bowel. Elastic constriction practiced in this manner prevents all possibility of extravasation, and does not interfere with the free manipulations of the operator, as is the case with clamps or the hands of an assistant, while the degree of compression that is necessary exerts no injurious effects on the vessels and tissues at the seat of constriction. Drainage was never resorted to, and the abdominal wound was always closed by deep interrupted sutures including the peritoneum. In all cases where partial or complete exventration was made necessary, the bowels were kept covered with warm gauze compresses. In all cases where complete exventration

became necessary, and where the bowels remained out of the abdomen for half an hour or more, a certain degree of shock was always noticed, and a number of animals died within a few hours after the operation, death being referable directly to this cause. For an external dressing we used iodoform ointment applied directly over the wound, and a compress of cotton, retained by a bandage, and a jacket made of coarse cloth. As a rule the sutures were removed at the end of six days, when the wound was usually found healed by primary union.

I. Artificial Intestinal Obstruction.

In imitation of the more common forms of intestinal obstruction in the human subject, due to congenital malformation or pathological conditions, the following kinds of obstruction were produced on animals: (1) stenosis, (2) flexion, (3) volvulus, (4) invagination. It is a noteworthy fact that even in cases where the obstruction was complete from the beginning, vomiting was moderate, and in some instances entirely absent. As vomiting constitutes one of the earliest and most conspicuous and persistent symptoms in most cases of intestinal obstruction in man, we can only explain its lesser intensity or complete absence in animals from the circumstance that animals suffering from this condition, as a rule, refuse all food and drink. As a rule, the tympanitis was also less marked than in the human subject.

1. Stenosis.

Circular narrowing of the lumen of the bowel was produced by excision of a semi-lunar piece of the intestinal wall and double suturing of the wound in a direction parallel to the intestine; and by circular constriction with bands of aseptic gauze.

a. Partial Enterectomy.

Experiment 1. Dog, weight thirty-nine pounds. A semi-lunar portion embracing half the circumference of the bowel removed from the convex surface, two inches above the ileo-cæcal valve. Wound closed in a longitudinal direction by Czerny-Lembert suture. The first two weeks the discharges from the bowels were fluid and dark in color, subsequently normal in color and consistence. Animal killed thirty-six days after operation. Body well nourished; abdominal wound indicated by a firm linear cicatrix. Omentum adherent at point of operation; lumen of bowel at point of operation reduced one-half in size; lumen of bowel above and below the contraction equal in size, showing that the stenosis had not furnished an obstacle to the passage of

intestinal contents. A few of the sutures remained attached, their free ends floating in the bowel.

Experiment 2. Large, full-grown cat. The same operation was performed on the concave side of the bowel about the middle of the ileum, a semi-lunar piece of the wall of the intestine with the corresponding mesentery being removed and the wound closed in a similar manner, which diminished the diameter of the lumen of the bowel to about one-eighth of an inch. It was noticed during the operation that the convex surface of the bowel over an area corresponding to the partial excision presented a cyanosed appearance. The animal died on the fourth day after operation, and the whole segment of the sutured bowel was found gangrenous, but no fluid in the abdominal cavity.

Experiment 3. Large, adult cat. In this case a segment of the ileum was emptied of its contents, and before cutting away a semi-lunar piece from the convex surface, a back-stitch, continuous suture was applied on the inner margin of the proposed line of incision, which left about one-third of the lumen of the bowel. After excision of the semi-lunar piece the margins of the cut surface were turned inwards and covered with serous surface by a continuous catgut suture. Several small passages occurred after the operation, but the animal died on the fourth day with symptoms of intestinal obstruction. The visceral wound was found healed, but the lumen had become so narrow from the inflammatory swelling of the tunics of the bowel that it was entirely inadequate for the passage of intestinal contents, and as a result of this obstruction the bowel had become considerably dilated above the point of operation.

Remarks.—These experiments illustrate conclusively that in wounds of the convex side of the intestine, where from the nature of the injury transverse suturing is impossible, longitudinal approximation and suturing can be safely done, provided at least one-half of the lumen of the bowel can be preserved. If the stenosis is carried beyond this point there is great danger that the inflammatory swelling following the operation will still further narrow the tube and lead to the most serious consequences due to intestinal obstruction, and place the visceral wound in the most unfavorable condition for the healing process.

Experiment No. 2 shows the great danger of interference with the blood supply from the mesentery in longitudinal suturing of wounds on the concave side of the bowel, as such a procedure is invariably followed by gangrene of the corresponding segment of bowel on the convex side.

b. Circular Constriction.

The following experiments were made to study the effect of circular constriction upon the circulation of the isolated constricted

loop of bowel. In all cases where the constriction was made with a gauze band, this was tied with the same degree of firmness, so as to determine whether the same degree of strangulation would produce identical results.

Experiment 4. Adult cat. A loop of bowel about the middle of the ileum, six inches in length, was tied with a band of aseptic gauze with sufficient firmness to cause slight congestion, but without interfering with a free arterial supply, as the arteries in the ligated portion continued to pulsate freely. The day after operation a few small fæcal discharges stained with blood. The cat died forty-eight hours after the operation. No rise in temperature was observed, and death was evidently caused by collapse from perforation. The loop of bowel showed gangrene on convex side equidistant from the point of strangulation, and a small perforation which had given rise to diffuse septic peritonitis. The whole visceral and parietal peritoneum was uniformly affected and the peritoneal cavity contained a considerable quantity of sero-sanguinolent fluid.

Experiment 5. Large, adult cat. A loop of the ileum of the same length was tied in a similar manner and with same degree of firmness. The animal absolutely refused food until the eighth day. Rise in temperature second and third day. Only one fæcal discharge on the second day. Killed eight days after operation. Abdominal wound completely united; no peritonitis. Four inches of bowel below the point of constriction showed that partial reduction had taken place. The gauze band was found completely covered with adherent omentum, and a thick layer of plastic lymph which formed a complete bridge connecting the intestine above and below the ligature. The ligated portion showed no evidence of defective circulation, and no ulceration underneath the ligature. The obstruction was complete, as no fluid could be forced through the bowel, and in proof that the same condition existed during life, it was found that the bowel above the constriction was considerably dilated, while below the strangulation it was empty and contracted.

Experiment 6. Large, Maltese cat. A loop of the ileum, six inches in length, tied in a similar manner. On the third day fæces stained with blood. On the same day the temperature, which had remained nearly normal until this time, rose to 105° F., and on the following day the animal died, having manifested symptoms of perforative peritonitis for twenty-four hours. Abdominal wound united; recent diffuse peritonitis. The abdominal cavity contained several ounces of sero-purulent fluid. Bowel above constriction distended with fluid contents, below the obstruction empty and slightly contracted. The greater portion of strangulated loop was found gangrenous and adherent to adjacent loops of bowel. Perforation had taken place in the middle of the loop on the convex surface, showing that gangrene had taken place first at this point and had extended from here towards the ligature.

Experiment 7. Adult dog, weight twenty-six pounds. In this case an opening was made in the mesentery through which a loop of the small intestine, six inches in length, was pushed. With sutures this opening was made

sufficiently small so that its margins produced slight strangulation. The dog remained perfectly well after the operation, and was killed on the twenty-second day. Abdominal wound completely healed. No signs of peritonitis. On searching for the seat of obstruction it was found that spontaneous reduction had taken place, the site of perforation in the mesentery being indicated by a recent cicatrix.

Remarks.—The post-mortem appearances in these cases demonstrate clearly that the gangrene was not produced by the primary mechanical strangulation, but that it depended upon consecutive pathological changes in the loop or its vessels. In experiment No. 5 the primary strangulation was fully as great as in the preceding experiment, and yet gangrene did not take place, and we have positive proof that vascular engorgement in the ligated portion was less intense from the fact that partial reduction took place. In all cases where gangrene resulted, it must not have been from deficient arterial blood supply, but from an obstruction to the return of blood through the veins. If defective arterial blood supply had been the immediate cause of the gangrene, we would have found more constantly gangrene of the entire loop, while every specimen illustrated that gangrene always commenced at a point where the return of venous blood met with the greatest resistance, viz., on the convex surface in the middle portion of the loop. As in cases of hernia, or in any other form of intestinal strangulation, where a firm constricting band surrounds the loop of bowel, the danger of complete strangulation is increased if by the peristaltic action additional portions of the intestine are forced through the ring; and the immediate cause of the gangrene is always referable to obstruction to the return of venous blood, which leads rapidly to œdema, complete stasis, and moist gangrene in that portion where the venous circulation is most seriously impaired. Violent peristalsis under such circumstances always aggravates the existing conditions, and is often the precursor of symptoms of complete strangulation. In such cases opiates act favorably by arresting peristaltic action, and in so doing may avert gangrene by preventing the causes which otherwise would have led to complete venous stasis.

2. Flexion.

As many instances are on record where flexion of the bowel constituted the cause of intestinal obstruction, this condition was artificially produced in animals either by making a partial enterec-

tomy by removing a wedge-shaped piece from one side of the bowel, or by bending the bowel upon itself acutely, and fixing it in this position with catgut sutures.

Experiment 8. Dog, weight sixty pounds. A wedge-shaped piece of the wall of the ileum was removed from the concave side with a corresponding portion of the mesenteric attachment, and after arresting the bleeding by tying several vessels with catgut, the wound was closed transversely by two rows of sutures. The excised piece measured one inch at its base, and the apex reached as far as the median line of the bowel. Immediately after excision, the convex portion of the bowel which had become acutely flexed by uniting the wound, presented a livid, congested appearance, and after tying the sutures the cyanosis increased. The area of disturbance of the circulation corresponded to the width of the base of the excised portion. About fourteen inches from this place a similar piece was excised from the convex side of the bowel, and the wound closed in the same manner. At this point the flexion was only slight, the mesenteric portion forming the prominence of the curve. On the third day the temperature rose to 105.6° F., and the following day the animal died with symptoms indicative of perforative peritonitis. On opening the abdomen, diffuse general peritonitis was found with numerous adhesions. Gangrene and perforation were found on the convex side directly opposite the place of first operation. Second visceral wound closed, and lumen of bowel at this point somewhat contracted, but permeable to fluids.

Experiment 9. Large, adult cat. Removed from convex side of ileum a triangular piece measuring one inch at its base, the apex reaching a little beyond the middle line of the bowel. Wound closed transversely by Czerny-Lembert sutures. After closure of the wound the bowel presented at point of partial resection an obtuse angle, the apex being formed by the mesenteric portion. The stools were bloody the second day after operation. The animal remained in excellent condition until it was killed, forty-three days after operation. Adhesions of loops of small intestines to abdominal wound, and of omentum and adjacent intestines at point of operation. The extent of flexion was found somewhat diminished, yet the concavity on convex side of bowel was well marked. Size of bowel above and below the operation was equal, showing that the flexion had not acted as a cause of obstruction. On opening the bowel a pouch-like bulging was found on the mesenteric side, which appeared to compensate for the narrowing caused by the artificial stenosis. Two of the deep sutures still remained attached to the inner surface of the bowel.

Experiment 10. Large, adult cat. In this case a loop of the middle portion of the ileum, four inches in length, was acutely flexed in such a manner that the peritoneal surfaces of the convex side were brought in contact, and in this position the bowel was fixed by a number of fine catgut sutures. No symptoms pointing towards intestinal obstruction were observed, and the animal was killed sixteen days after the operation. Wound was found completely united, and no signs of peritonitis. The angle of flexion had somewhat diminished, but otherwise the bowel was adherent in position left after

operation. The bowel presented no dilatation above nor contraction below the flexion, showing that complete permeability of the canal at the point of flexion was quickly restored.

Remarks.—The partial excision on concave side of bowel in experiment No. 8, illustrates the danger of suturing wounds in this locality where the blood supply from the mesentery is likewise impaired, as gangrene of the remaining portion of the bowel is almost certain to take place. In all wounds on this side of the bowel more than half an inch in length, there is also another great danger which attends transverse suturing, viz., stenosis, which may become the cause of intestinal obstruction. As the small intestines naturally describe quite a strong curve with the concavity on the mesenteric side, closure of a wound involving this portion of the bowel gives rise to acute flexion which, at least during the process of healing, must cause more or less obstruction, until by yielding of the opposite portion of the intestinal wall an adequate dilatation of the calibre of the tube has taken place. A considerable portion of the wall on the convex side of the bowel can be removed and sutured transversely until the bowel has been transformed into a straight tube, and a wound an inch in length will make only a slight flexion which furnishes no serious mechanical obstacle to the passage of the intestinal contents. In this connection the question arises: Does simple flexion, even if acute, without diminution of the lumen of the bowel, give rise to symptoms of obstruction? I have made numerous flexions when performing operations for establishing intestinal anastomosis, and in most instances satisfied myself by examination of the specimens that fluids passed them without great difficulty. If the bowel at the point of flexion remains free, certain portions of its wall will yield to pressure of the fluid intestinal contents, and gradually the lumen of the bowel will become restored. If, on the other hand, the entire circumference of the bowel at the point of flexion has become fixed and immovable by inflammatory adhesions or other pathological products, a compensating dilatation becomes impossible, and the flexion becomes a direct and serious cause of obstruction.

3. Volvulus.

This condition, only another form of flexion, was experimentally produced by rotating a loop of intestine one and a half or two times around its axis, and retaining it in this position by a number of fine

sutures, which were applied in places at the base of the volvulus, where fixation was most required.

Experiment 11. Dog, weight twelve pounds. A loop of the ileum, eight inches in length, was brought out through a small incision and the tubes turned around their axis twice and the twist maintained by two catgut sutures. The constriction was sufficiently firm to cause considerable venous engorgement in the twisted loop. The dog manifested no unpleasant symptoms after the operation. The specimen was not obtained, as after a few days the dog ran away.

Experiment 12. Medium-sized adult cat. In this case the volvulus was made by twisting a loop of the ileum, about four inches in length, twice around its axis, and retaining it in this position by a number of fine silk sutures. Vomited several times during the first day. The first three days in taking the temperature in the rectum, the thermometer when taken out was bloody. The first two days the temperature was normal, followed by an increase to 104.6° and 103.2° F. the two succeeding days; then it became normal. No constipation; appetite good throughout the whole time. Animal killed twenty-two days after operation. Abdominal wound completely united; no peritonitis. Volvulus remains as after operation, with the exception that where the bowel had been flattened by the twisting it had, at least partially, resumed its tubular form. Serous surfaces where approximated had become firmly adherent at point of constriction, size of bowel considerably diminished. The twisted loop contained liquid fæces. Connecting the specimen with the faucet of a hydrant, water could be forced through, but on increasing the force of the current the peritoneum ruptured extensively in a longitudinal direction to point of partial obstruction.

Remarks.—These experiments are interesting, inasmuch as the primary constriction produced in making and maintaining the volvulus, which was sufficient to cause venous engorgement in the twisted loop, must have been only of short duration, the disappearance of the effects of constriction being undoubtedly due to the gradual yielding of the sutured parts. While the faulty axis of the twisted loop was maintained by the sutures, the circulation improved and remained in a sufficiently vigorous condition to adequately nourish the most distant portions of the volvulus. While it was found difficult to force fluid through a specimen of volvulus during life, propulsion of the intestinal contents by peristaltic action was carried on in a satisfactory manner, as the bowel above the volvulus was not dilated, and contained no abnormal amount of fluid, and the animal manifested no symptoms indicative of intestinal obstruction.

4. Invagination.

The most frequent and, from a surgical standpoint, the most important form of intestinal obstruction is invagination. Leichten-

stern and Leubuscher have made careful experimental studies to explain the mechanism and pathological conditions which give rise to this kind of intestinal obstruction; but in the following experiments this part of the subject was ignored, and the invaginations were made by direct manipulation. It was found impossible to make an invagination at any point, as long as the bowel was in a condition of contraction, consequently it was always found necessary to wait until the peristaltic wave had passed by, or to cause relaxation by firm pressure continued for several minutes. Usually, it was found easy to produce an invagination of the bowel, when in a state of relaxation, by indenting one side of the bowel, and pushing the pouch forward with a blunt instrument until the entire lumen of the intestine had passed into the section of the bowel below. After this was accomplished, further invagination was readily effected by manipulation, consisting in pushing gently the intussusceptum and intussuscipiens in opposite directions. After I had learned by experience that disinvagination frequently takes place spontaneously, I resorted sometimes to suturing of the intussusceptum to the neck of the intussuscipiens for the purpose of maintaining the invagination. But even this expedient did not always succeed in retaining the malposition, as spontaneous reduction was observed in several of these cases.

Experiment 13. Adult cat. The lower portion of the ileum and the cæcum and upper portion of the colon were drawn forward into an incision through the linea alba, and five inches of the ileum were pushed into the colon through the ileo-cæcal valve, when the parts were replaced and the abdominal wound closed. For six days the animal had a temperature from 102.6° to 105° F., and suffered from tenesmus. The stools contained mucus and blood. After the sixth day the symptoms due to invagination subsided, and were replaced by symptoms of peritonitis. The animal was killed twenty-two days after operation. Great emaciation; abdominal wound completely united; diffuse purulent peritonitis. The disease had evidently commenced in the ileo-cæcal region, as at this point the pathological changes were found most advanced. Complete spontaneous reduction of the invagination; colon greatly distended, and intensely congested.

Experiment 14. Large, adult cat. Invagination was made in the lower part of the ileum. Length of intussusceptum three inches. For nine days the scanty fæcal discharges contained mucus and at times blood. On the ninth day the temperature registered 105° F.; absolute refusal of food, and only occasional vomiting; death on the thirty-third day after invagination. Abdominal wound healed; small ventral hernia; no peritonitis. Apparently, the greater portion of the intussusceptum had disappeared by sloughing, and

the subsequent healing process had produced an acute flexion at the neck of the intussuscipiens. Firm adhesions between peritoneal surfaces in the concavity of the flexion, nearly an inch in length. Above this point the intestine was enormously dilated and distended with fluid contents. Below the obstruction the bowel was found contracted and empty. Water could not be forced through the obstruction from either direction. On slitting open the bowel in a longitudinal direction, it was found that the lumen at the point of flexion was contracted to such an extent that only a fine probe could be passed. On the concave side of the flexion the mucous membrane presented a prominence marked by a number of longitudinal ridges. These folds had undoubtedly acted like valves in completely preventing the passage of intestinal contents, and later, the injection of water. Death in this case resulted from intestinal obstruction caused by cicatricial contraction after the sloughing of the invaginated portion of the bowel.

Experiment 15. Adult cat. Two inches of the ileum were invaginated into the colon and fixed by two fine silk sutures at the neck of the intussuscipiens. For two days after the invagination the stools were scanty and contained mucous and blood. On the third day the abdominal cavity was re-opened by an incision along the outer border of the right rectus muscle, and the invaginated bowel drawn forward into the wound. No peritonitis. The bowel at point of operation was very vascular, and the neck of the intussuscipiens covered with plastic exudation. The sutures were removed and the rectum and colon distended with water for the purpose of effecting reduction. As soon as the colon had become thoroughly distended the adhesions gave way with an audible noise, and complete reduction followed in such a manner that the portion last invaginated was first reduced. After reduction had been accomplished the injection was continued to test the competency of the ileo-cæcal valve. As soon as the cæcum was well distended the fluid passed readily through the valve into the small intestines, showing that the valve had been rendered incompetent by the invagination. The force required to overcome the adhesions in the reduction of the invagination was sufficient to rupture the peritoneal covering of the large intestines in three different places, the rents always taking place parallel to the bowel. The animal died on the following day with symptoms of diffuse peritonitis.

Experiment 16. Ascending invagination in a cat. A few inches above the ileo-cæcal region the ileum was invaginated in an upward direction to the extent of two inches. At the time the invagination was made the intussuscipiens contracted firmly. In consequence of this, a tear occurred in its peritoneal covering in a direction parallel to the bowel. The stools were few and scanty. On the fourth day the animal died of perforative peritonitis. Abdominal wound not united, but the peritoneal wound closed by omental adhesions. Spontaneous reduction of half an inch of the invagination had taken place. Reduction by traction was found impossible on account of firm adhesions about the neck of the invagination. Recent diffuse peritonitis caused by two perforations, one at the neck of the intussusceptum on mesenteric side, and the other a little to one side of this one and on proximal side of the bowel.

The perforation resulted from beginning sloughing of the invaginated portion of the bowel. About two inches above the invagination the bowel was acutely flexed towards the mesenteric side by recent firm adhesions. Flexion was undoubtedly caused by circumscribed plastic peritonitis and increased peristalsis.

Experiment 17. Large, adult cat. Descending invagination of ileum to the extent of two inches in the upper portion of this part of the bowel. Second and third days the scanty discharges from the bowel bloody. Temperature from second day after operation varied between 103.4° and 105.4° F. Death from perforative peritonitis on the seventh day after invagination. Abdominal wound united. Recent diffuse peritonitis from a perforation at the neck of the invagination on the mesenteric side. Gangrene of intussusceptum and partial separation which had again caused a sharp flexion of the bowel at the neck of the invagination. Above the seat of obstruction the bowel dilated and distended with fluid contents; below empty and contracted.

Experiment 18. Young cat. Invagination of ileum into ascending colon to the extent of three inches. For a week after operation frequent tenesmus, followed by mucous discharges mixed with blood. The temperature during this time varied from 102.6° to 105° F. After this the animal improved and was in good condition when killed fourteen days after operation. Abdominal wound united. No omental adhesions or peritonitis. Firm union between the serous surfaces. No dilatation of bowel above seat of obstruction. Intussusceptum not gangrenous, its lumen about the size of an ordinary lead-pencil. It was found impossible to reduce the invagination by traction or by forcible injection of fluid from below. When the traction was increased, the peritoneal surface of the neck of the intussuscipiens ruptured in a longitudinal direction.

Experiment 19. Large, adult cat. Six inches of the ileum were invaginated into the colon. Frequent bloody discharges until the third day, when the abdomen was reopened and the neck of the intussuscipiens exposed to sight, so as to observe directly the mechanism of disinvagination by rectal injection of water. As soon as the colon was well distended the adhesions at the neck of the intussuscipiens began to give way, and complete reduction followed, as the adhesions gave way under the pressure from below. The abdominal wound was again closed and dressed in the usual manner. The animal recovered completely from the operation, and was killed twenty-four days after the first operation. Abdominal wound well united. In the ileocæcal region, numerous adhesions around the portion of bowel which had been invaginated and subsequently reduced.

Experiment 20. Invagination of colon into colon was commenced about the middle of the bowel, and advanced as far as the cæcum. Second day bloody discharges from the bowels. Animal killed five days after operation. External wound united only on peritoneal side. Invagination completely reduced. Localized plastic peritonitis limited to the portion of the bowel which had been invaginated; otherwise peritoneum and intestines in a healthy condition.

Experiment 21. Invagination of colon into colon to the extent of four inches, in a cat. The subsequent symptoms only for a short time indicated

the existence of invagination, which after they had subsided, were followed by evidence of peritonitis. Death occurred on the nineteenth day after the invagination. Abdominal wound well united; diffuse purulent peritonitis; under surface of diaphragm covered with plastic lymph. Although sought for, no perforation could be found in the disinvaginated bowel, but as the peritonitis appeared to have started at the site of operation, it is probable that infection took place through the paretic walls of the disinvaginated bowel.

Experiment 22. Same kind of invagination made in a cat as in the preceding case. For two days the stools were frequent, scanty, and contained mucus and blood. After this the animal remained in good condition until it was killed thirty-five days after the invagination. Abdominal cavity showed no trace of inflammation. The invagination was completely reduced and the entire colon presented a normal appearance.

Remarks.—With the exception of experiment No. 16, the invagination was always made in a downward direction. In the case of ascending invagination, gangrene of the intussusceptum and perforation resulted in death from diffuse peritonitis on the fourth day after partial spontaneous reduction had taken place. In experiments Nos. 15 and 19, both cases of ileo-cæcal invagination, complete reduction was effected by distention of the colon with water; in the first case the force required to accomplish this result was sufficient to produce multiple longitudinal lacerations of the peritoneal surface of the distended bowel, which undoubtedly were responsible for the death on the following day from diffuse peritonitis; while in the second case no such accident occurred, and the animal recovered, although the abdominal wound was re-opened for the purpose of observing the mechanism of reduction by this method of procedure. In one case of ileo-cæcal invagination, experiment No. 18, the intussusceptum remained *in situ* after the invagination, and became so firmly adherent to the intussuscipiens that even in the specimen, reduction by traction was found impossible. In this case, although the lumen of the invaginated portion barely permitted the introduction of an ordinary lead pencil, no symptoms of obstruction were manifested during life, and the bowel above the invagination was not found dilated after death. In experiment No. 14, the sloughing of the intussusceptum led to cicatricial contraction of the bowel and flexion at site of invagination, conditions which resulted in death from obstruction twenty-three days after invagination.

The great danger which attends sloughing of the invaginated portion is circumscribed gangrene and perforation of the intussuscipiens at the neck, and death from perforative peritonitis, as

illustrated by experiments Nos. 16 and 17. Experiment No. 16 illustrates that ascending invagination, should it occur, is not more likely to be reduced spontaneously than the more common form of descending invagination. These experiments also demonstrate conclusively that the danger attending the invagination increases the higher it is located in the intestinal canal, being greatest when it is situated high up in the tract of the small intestines, and gradually less as the ileo-cæcal region is approached. The ileo-cæcal form is less dangerous, as spontaneous reduction is more likely to take place; and gangrene of the intussusceptum, when it occurs, does so after a longer time, after firm adhesions about the neck of the intussuscipiens have formed, a condition which is well adapted to prevent perforation. Of the three invaginations of the colon, experiments Nos. 20, 21 and 22, complete spontaneous reduction took place in all of them from the first to the fourth day, and in only one of them was the result fatal, in experiment No. 21, where purulent peritonitis, either from infection through the operation wound or, what is more probable, through the damaged wall of the colon occurred, and was the cause of death on the nineteenth day after the invagination. Experiments Nos. 15 and 19 prove both the danger and the utility of distention of the colon in cases of ileo-cæcal and colonic invaginations. As a rule, the longer the invagination has existed the firmer the adhesions, and consequently the greater the danger of relying too persistently on this measure in reducing the invagination. In resorting to this expedient in the reduction of an ileo-cæcal invagination, it is of the greatest importance to relax the abdominal wall completely by placing the patient fully under the influence of an anæsthetic; and to add to the distending force as much as possible by gravitation, the patient should be inverted and the injection should always be made very slowly and with requisite care to prevent rupture of the peritoneal coat by rapid over-distention. When the obstruction is located beyond the ileo-cæcal valve, no reliance can be placed upon this measure, as can be seen from the following experiments made to determine the

Permeability of the Ileo-Cæcal Valve.

Experiment 23. While completely under the influence of ether an incision was made through the linea alba of a cat, sufficiently long to render the ileo-cæcal region readily accessible to sight. An incision was made into the ileum just above the valve, and by gently retracting the margins of the

wound, the valve could be distinctly seen; water was then injected per rectum, and as the cæcum became well distended, it could be readily seen that the valve became tense and appeared like a circular curtain preventing effectually the escape of even a drop of fluid into the ileum. The competency of the valve was only overcome by *over-distention* of the cæcum which mechanically separated its margins, which allowed a fine stream of water to escape into the ilenm. The insufficiency of the valve was clearly caused by great distention of the cæcum. That snch a degree of distention is attended by no inconsiderable danger was proved by this experiment, as the cat was immediately killed, and on examination of the colon and rectum a number of longitudinal rents of the peritoneal coat were fonnd.

Experiment 24. In this experiment, a cat was fully narcotized with ether and while the body was inverted water was injected per rectum in sufficient quantity, and adequate force by means of an elastic syringe, to ascertain the force required to overcome the resistance offered by the ileo-cæcal valve. Great distention of the cæcum could be clearly mapped out by percussion and palpation before any fluid passed into the ileum. As soon as the competency of the valve was overcome, the water rushed through the small intestines, and having traversed the entire alimentary canal issued from the mouth. About a quart of water was forced through in this manner. The animal was killed and the gastro-intestinal canal carefully examined for injuries. Two longitudinal lacerations of the peritoneal surface of the rectum, over an inch in length, were found on opposite sides of the bowel.

Experiment 25. This experiment was conducted in the same way as the foregoing, only that the cat was not etherized. More than a quart of water was forced through the entire alimentary canal from anus to mouth. The animal was not killed, and lived for eight days, but suffered the whole time with symptoms of ileo-colitis. A post-mortem examination was not made in this case, although the symptoms manifested during life leave no doubt that they resulted from injuries inflicted by the injection. It will thus be seen that in the three cases where fluid was forced beyond the ileo-cæcal valve, in two of them the post-mortem examination revealed multiple lacerations of the peritoneal coat of the large intestines, while the third animal sickened immediately after the experiment was made, and died from the effects of the injnries inflicted eight days later. The injection of water beyond the ileo-cæcal valve in the treatment of intestinal obstruction must therefore be looked upon in the light of a dangerous expedient and should never be resorted to.

II. Enterectomy.

It still remains an open question to what extent resection of the small intestines can be performed with impunity. It is true that Koeberlé, Kocher and Baum have successfully removed respectively 205 cm., 160 cm., and 137 cm. of the small intestine in the human subject; but while two of the patients do not appear to have suffered any ill effects in consequence of the removal of such a large surface

for digestion and absorption, in Baum's case death, which supervened six months after the operation, was attributable clearly to marasmus, brought about by the extensive intestinal resection. As in a number of pathological conditions of the intestinal canal, where the wounds are large and in close proximity, such as multiple strictures, gangrene, and multiple gunshot wounds, it may be necessary to resort to extensive resection, it becomes an important matter for the surgeon to know how much of the intestinal tract can be removed without any immediate or remote ill consequences.

The immediate danger attending such an operation is the traumatism, which of course, will be proportionate to the length of the piece of intestine removed; while the remote consequences are due to impairment of the functions of digestion and absorption caused by the shortening of the intestinal canal. With the view of obtaining additional light on these important questions the following experiments were undertaken:

Experiment 26. Dog, weight twenty-two pounds. Mesentery divided into four portions and tied with catgut, and thirty inches of the ileum from near the ileo-cæcal region upwards excised, and ends sutured together by Czerny-Lembert sutures. Abdominal wound failed to unite, and a copious sero-sanguinolent discharge escaped from it the last day. Death on fifth day from peritonitis. Peritoneal adhesions in abdominal wound only partial; omentum adherent to wound. Intestines firmly adherent to omental stump. Circumscribed gangrene of bowel on convex side at site of operation. Recent diffuse peritonitis caused by perforation.

Experiment 27. In a cat, twelve inches were removed from the middle of the ileum, and the ends united by a double row of sutures; mesenteric vessels tied *en masse* with one catgut suture. The animal never rallied from the operation, and died of the shock the same night.

Experiment 28. Dog, weight thirty-six pounds. Mesentery tied in several sections with catgut ligatures; ileum divided just above the ileo-cæcal valve and six feet of the small intestines excised, and the ends united by Czerny-Lembert sutures. On the third day the fæcal discharges were bloody. Although the appetite remained good, and the dog was allowed to eat as much as he desired, he lost several pounds in weight during the first week. On the third day the abdominal wound opened as the sutures had cut through and required re-suturing. After this time the wound healed kindly. Three or four fluid fæcal discharges during twenty-four hours. The character of the discharges remained the same, and several microscopic examinations made at different times revealed the presence of free undigested fat. The dog was kept busy eating most of the time, and although the most nourishing food was furnished, he emaciated to a skeleton. He was killed one hundred and sixty-one days after the operation. Marasmus extreme, hardly a trace of fat could be found any-

where in the tissues. Stomach enlarged to three or four times its normal size, and distended with food. A slight thickening of the wall of the gut indicated externally the site of suturing, and the lumen of the bowel at this point was slightly diminished in size. At point of operation a loop of intestine was found adherent and somewhat contracted. The remaining portions of the small intestines, only forty-five inches in length, seemed to have undergone compensatory hypertrophy, as the coats were much thickened and exceedingly vascular. At the seat of suturing, the mucous membrane presented a slight circular prominence. Pancreas, liver and spleen were normal in size and appearance.

Experiment 29. Medium-sized, adult dog. Mesentery tied in several sections, and eight feet and two inches of the small intestines from ileo-cæcal region upwards excised and ends sutured in the usual manner. On the following day the dog vomited, and blood was seen to escape from the abdominal wound. Death three days after operation. The abdominal cavity was filled with fluid and coagulated blood, which on closer inspection was found to have escaped from one of the stumps of the mesentery, where the catgut ligature had slipped off.

Experiment 30. Scotch terrier, weight ten pounds. Mesentery ligated in part with catgut ligatures, the ileum divided four inches above the ileo-cæcal region, and fifty inches of the small intestines excised, and the continuity of the intestinal canal restored by the usual method of suturing. Some difficulty was experienced in suturing, as the lumen of the upper end was considerably larger than that of the lower. Until four weeks after the operation the dog, although eating well, seemed to become more and more emaciated. After this time he gained somewhat in weight until killed forty-seven days after the resection. During the whole time the fæces were either fluid or only semi-solid, and at different times contained free, undigested fat. Appetite most of the time voracious. No adhesions to abdominal wound. Omentum adherent to visceral wound and to bowel. The site of operation was indicated by a slight depression on the surface of the bowel. On palpation a ring-like thickening was felt corresponding to the united ends of the bowel. Bowel above seat of resection somewhat enlarged. On cutting into the bowel the point of union was indicated by a circular prominence of mucous membrane. Nine of the deep sutures were found still attached to the mucous membrane. The entire tract of the small intestines which remained measured only two feet and ten inches in length.

Experiment 31. Adult Maltese cat. The mesentery was tied in five sections with catgut ligatures corresponding to twenty-nine inches of the ileum which was excised. Previous experience in circular enterorrhaphy had satisfied me that perforation is most likely to take place on the mesenteric side of the bowel, where, on account of the triangular place made by the reflections of the peritoneum, the muscular coat is not covered by serous membrane. To obviate this difficulty I secured a continuity of the serous covering of the ends of the bowel before suturing, by drawing the peritoneum over this raw surface by a fine catgut suture. The mesentery was detached

only to a sufficient extent to apply the second row of sutures. The fine catgut suture to approximate the edges of the peritoneum was applied near the margin of the divided end of the bowel, so that the knot did not interfere with the accurate coaptation of the serous surface between the deep and superficial row of sutures. This modification of circular suturing was adopted for the first time in this case. Although the animal manifested no untoward symptoms, and the appetite remained good, the marasmus was progressive until the time of killing, twelve days after the excision. Abdominal wound not completely united. Intestinal wound, which was two inches above the ileo-cæcal region, completely healed. The sutured surface was adherent to a loop of bowel which caused a sharp flexion. Intestine above this point somewhat dilated and partially distended with fæcal accumulation. Slight contraction of the lumen of bowel by circular bulging of mucous membrane, in which most of the deep sutures remained fixed. The post-mortem appearance pointed to partial obstruction at point of flexion; remaining portion of small intestines measured only twenty-one inches in length.

Experiment 32. Medium-sized Maltese cat. Mesentery tied in sections, and thirty-four inches of the small intestines excised and the divided ends united in the same manner as in the last case, special care being taken to secure an uninterrupted peritoneal surface for divided ends before suturing. Appetite remained good, but progressive marasmus, which appeared at once, continued and proved the direct cause of death twenty-one days after the excision. Abdominal wound firmly united. No peritonitis. Visceral wound completely united; intestine at site of operation covered with adherent omentum.

I. Excision of Colon.

Experiment 33. Large, black cat. The meso-colon was divided in numerous sections, and each part separately tied with a catgut ligature. As the meso-colon was very short, a number of the ligatures slipped off and had to be replaced by fine silk ligatures. The entire colon and about two inches of the lower end of the ileum were excised. As it was found impossible to unite the bowel on account of the deep location of the rectal end, it became necessary to close the distal or rectal end by inverting its margins and applying a continuous suture. An artificial anus was established by stretching the iliac or proximal end into the abdominal wound. Death from shock a few hours after the operation.

Experiment 34. Medium-sized dog. Resection of entire colon and three inches of ileum. Meso-colon divid d into sections and ligated with silk ligatures. In order to enabl circular enterorrhaphy it was found necessary to excise a triangular piece from large distal end, so as to make its lumen correspond to that of the divided ileum. After this was done and the lateral wound closed by two rows of sutures, the ends of the bowel were united in the usual manner. Death from shock six hours after operation.

Experiment 35. Excision of entire colon and two inches of ileum in a cat. Excision of triangular piece from distal end, to narrow the bowel suffi-

ciently so that its lumen should correspond to that of the ileum. The ileum and rectum were then united by Czerny-Lembert sutures. The animal never rallied from the prolonged operation, and died of shock two hours later.

Remarks.—The results of these experiments speak for themselves. In all cases of extensive resection of the small intestines where the resected portion exceeded one-half of the length of this portion of the intestinal tract, where the animals survived the operation, marasmus followed as a constant result, although the animals consumed large quantities of food. In all of these cases defective digestion and absorption could be directly attributed to a degree of shortening of the digestive canal incompatible with normal digestion and absorption. Only one of these animals (experiment No. 27) died from shock a few hours after operation. Another death resulted from the trauma, in experiment No. 29, where fatal hæmorrhage occurred from one of the mesenteric vessels, where the catgut ligature became displaced from shrinkage of the included mesenteric tissues. When the vessels of the omentum or mesentery are tied *en masse* there is always danger from this source, and to prevent this accident it becomes necessary not to include too much tissue, and to tie firmly with fine threads of aseptic silk. After I commenced to tie in this manner, I encountered no further difficulty in arresting and preventing hæmorrhage in operations requiring incision of these tissues. Although the large artery running parallel with the bowel where the mesentery is attached was excised in every case with the intestine, gangrene and perforation occurred only in experiment No. 26. The post-mortem appearances after extensive enterectomies indicated that the portion of bowel which remained underwent compensatory hypertrophy, but that as a rule the increased functional activity was not adequate to make up for the great anatomical loss. In all instances where the animal recovered from the operation, the discharges from the bowels were frequent, fluid or semi-fluid, and contained undigested food, among other substances, free undigested fat, showing that the intestinal secretions play an important role in the digestion of fat. As an approximate estimate the statement can be ventured that in dogs and cats, the excision of more than one-third of the length of the small intestines is dangerous to life, as it is followed by marasmus, which sooner or later results in death. As all three cases of excision of the colon proved fatal from shock in from two to six hours, it can be safely

asserted that this operation is impracticable, and is invariably followed by death from the immediate results of the trauma.

2. Physiological Exclusion.

As extensive resections of the intestines are always attended by great risks to life from the trauma, I concluded to study the subject of sudden deprivation of the system of a great surface for digestion and absorption, by eliminating or diminishing the cause of death from this source by leaving the intestine, but by excluding permanently a certain portion from participating in the functions of digestion and absorption; in other words, by resorting to physiological exclusion. These experiments were also made to determine the tissue changes which would take place in the bowel thus excluded, and to learn if under such circumstances accumulation of intestinal contents would become a source of danger, as had been feared by the older surgeons. The complete interruption of passage of intestinal contents either by section and closure of the bowel, or by making an intestinal obstruction of some kind, and the restoration of the continuity of the physiologically active portion of the intestinal canal, was established by suturing the proximal end of the high section with the distal end of the lower section, or by implanting the proximal end into the bowel lower down, the intervening portion of the intestinal tract in either case thus becoming the excluded portion.

Experiment 36. Large cat, weight nine pounds. Double division of small intestines, upper section made about eight inches below the pylorus, and the lower three feet lower down; the portion of bowel between these circular sections was closed at both ends, and the continuity of the intestinal canal restored by suturing the open ends in the usual manner. In this way three feet of the small intestines were isolated and completely excluded from the digestive canal. The intervening portion was emptied of its contents as completely as possible before its ends were closed by suturing. The animal died on the fourth day after the operation. A small perforation of the sutured bowel on the mesenteric side was found, otherwise the visceral wound was found well united. The perforation had given rise to diffuse peritonitis which was the immediate cause of death.

Experiment 37. Dog, weight thirty-two pounds. The jejunum was divided four feet above the ileo-cæcal region, and the distal end closed. Jejuno-colostomy was made by implanting the proximal end into a slit made in the convex side of the ascending colon, large enough to correspond to the circumference of the jejunum. The implanted end was fixed in its position by two rows of sutures. The animal never appeared to rally from the effects of the operation, and died at the end of the next day. The abdominal cavity

was found filled with blood, which must have escaped from a mesenteric vessel, from which probably the catgut ligature had slipped. The excluded portion, that is, that portion intervening between the circular section and the point of implantation, was found quite empty of intestinal contents, but slightly distended with gas. Implanted end perfectly retained by sutures, and slight adhesions between serous surfaces had already taken place. Death in this case was the result of secondary hæmorrhage.

Experiment 38. Dog, weight thirty-five pounds. Divided the ileum just above the ileo cæcal region, and closed both ends of the bowel. Ileo-colostomy was done by making an incision about an inch and a half in length on concave side of ileum, forty-four inches above the division, and a similar slit on convex side of ascending colon, and uniting these wounds by Czerny-Lembert sutures, thus excluding from the intestinal circulation forty four inches of the bowel. The day after the operation the fæces contained blood. During the progress of the case it was frequently noted that the stools were thin, sometimes liquid. Appetite remained good, and the animal was well nourished at the time of killing, twenty-five days after operation. Abdominal wall well united. The omentum and a few intestinal loops adherent to inner surface of wound. The excluded portion contracted to more than one-half of its usual size, atrophic, and not nearly as vascular as remaining portion of intestinal canal, the two blind ends adherent to each other and to adjacent loops. The excluded portion contained in its blind end a few sharp fragments of bone. The new opening between the ileum and colon, about the capacity of the lumen of the ileum, surrounded by a prominent margin of mucous membrane, which somewhat resembled the ileo-cæcal valve to which still remained attached about ten of the deep sutures. The coats of both bowels at points of approximation thickened by inflammatory exudation.

Experiment 39. Young cat. The ileum was divided about thirty inches above the ileo-cæcal region; the distal end closed and proximal end laterally implanted into the convex side of the transverse colon, where it was fixed by a double row of sutures. Before implantation, the continuity of the peritoneal surface was procured by drawing the peritoneum with a fine catgut suture over the denuded space left after detachment of the mesentery. Although the animal partook freely of food, progressive marasmus set in, to which the cat succumbed eleven days after the operation. Abdominal wound completely healed. Union of implanted ileum with colon perfect. No peritonitis. Excluded portion empty. Bowel above implantation somewhat dilated.

Experiment 40. Young, but full-grown cat. Physiological exclusion of two-thirds of the small intestines and the entire colon, by division of the small intestines at the junction of the upper with the middle third. Closure of distal end, and restoration of continuity of the shortened intestinal tract by making a jejuno-rectostomy. The implantation was made into the upper portion of the rectum at a point opposite the meso-rectum. Previous to section and suturing, the portion of bowel to be excluded was emptied of its contents. Animal died two days after operation. No peritonitis. Slight adhesions between the serous surfaces of rectum and implanted jejunum; excluded portion empty.

Experiment 41. The entire ileum was excluded, in a cat, by dividing the intestine at its junction with the jejunum, closure of distal end and making a jejuno-colostomy by implantation of the proximal end into a slit of the transverse colon at a point opposite the meso-colon. The cat remained in good condition until killed fifteen days after operation. No vomiting, and movements from bowels normal. Abdominal wound completely closed ; no peritonitis ; jejunum at point of implantation firmly united ; new opening in colon the size of the lumen of the ileum. Excluded portion empty, contracted and anæmic.

Experiment 42. Large mastiff. The small intestine was divided six and a half feet above the ileo-cæcal region, the distal end closed, and the proximal end implanted into an incision of the transverse colon large enough to receive it at a point opposite the meso-colon. Suturing was done exclusively with fine silk. For three weeks the dog appeared quite well, ate well, and the discharges from the bowels were normal. From this time the emaciation, which commenced soon after the operation was done, began to increase rapidly, the animal began to refuse food, and died of marasmus thirty-two days after operation. No peritonitis. Excluded portion empty, and reduced one-half in size ; the coats of the bowels very much attenuated, and the vessels hardly half the normal size. Only three feet and five inches of the small intestine remained for physiological action. New opening in colon sufficiently large to permit the introduction of the index finger as far as the first point. On slitting open the colon, the point of juncture with the jejunum upon the inner surface was marked by a slight ridge of mucous membrane, which bore a faint resemblance to the ileo-cæcal valve.

Remarks.—For some reason which I am unable to explain satisfactorily, in animals where the same length of intestine was physiologically excluded, as in the resection experiments, the appetite never became so voracious, and the remaining portion of intestine did not undergo the same degree of compensatory hypertrophy as in the excision experiments. Theoretically, two explanations might be advanced : first, in shortening the intestinal canal by resection, an extensive vascular district is cut off by ligation of the mesentery, and it is only reasonable to assume that the circulation in the remaining branches of the mesenteric artery would be increased, and consequently the functional activity of the organs supplied by them augmented ; second, in cases of physiological exclusion by lateral apposition, it is possible that at least some of the fluid contents reached the excluded portion from which a certain amount might still have become absorbed. The exclusion was complete or nearly so, hence we must conclude from the post-mortem appearances, that in nearly every instance, the excluded portion presented an atrophic, contracted condition, and was only sparingly

supplied with blood-vessels. From a practical standpoint these experiments teach us that a limited portion of the intestinal canal can be permanently excluded from the processes of digestion and absorption in proper cases, by operative measures without incurring any risk of fæcal accumulation in the excluded part. These experiments demonstrate also that physiological exclusion of a certain portion of the intestinal tract is a less dangerous operation than excision, and that in certain cases of intestinal obstruction, where excision has been heretofore practiced, it can be resorted to as a substitute for this operation in cases where excision is impracticable, or where the pathological conditions which have caused the obstruction do not in themselves constitute an intrinsic source of immediate or remote danger to life. The post-mortem appearances of the specimens of these experiments tend to prove that as long as any of the contents of the intestines reach the excluded portion, the peristaltic or anti-peristaltic action in that part is effective in forcing it back into the active current of the intestinal circulation.

III. Circular Enterorrhaphy.

During my experimental work I became convinced that circular enterorrhaphy as it is now commonly performed is attended by three great sources of danger: 1. Perforation at the junction not covered with peritoneum ; 2. Length of time required in performing the operation; 3. The number of sutures required.

To obviate the danger of perforation at the junction of the bowel not covered by serous membrane, I resorted to peritoneal suturing before uniting the bowel, by drawing the peritoneum over the denuded space caused by the limited detachment of the mesentery, by a fine catgut suture applied near the free margin of the bowel as described before. This requires but little time, and secures for the whole circumference of the bowel a peritoneal covering, so that after the bowel has been sutured the great rule inaugurated by Lembert (serosa against serosa) has been carried out to perfection. The results showed that this little modification of the ordinary method of suturing yielded more satisfactory results, and should therefore be adopted in all cases where circular enterorrhaphy is done with Czerny-Lembert or Lembert's sutures. Time plays an important part in determining the results of all operations requiring abdominal section; and this is especially true in all operations for intestinal

obstruction, as this class of patients is usually greatly exhausted before consent to an operation can be obtained. With a patient exhausted from an acute attack of obstruction of the bowels, it becomes exceedingly important to consume as little time as possible in the operation, as the shock incident to a long operation may itself determine a fatal result. Even after I had acquired a fair degree of manual dexterity in suturing the bowel, I seldom spent less than an hour in making a circular enterorrhaphy with a double row of sutures. In opening the abdomen for intestinal obstruction, a considerable length of time is usually spent in finding the obstruction; and when this is found and the patient manifests symptoms of collapse, a radical operation, which for its performance requires an hour or more, is often abandoned and the operation finished by making an artificial anus, which at the present time must be looked upon as a reproach upon good surgery.

The last objection to the Czerny-Lembert method of suturing requires no argument. Any surgeon who hastily transfixes the bowel with a needle from thirty to forty times in applying the Lembert suture is liable to perforate the whole thickness of its walls once or more; and if silk is used as suturing material, the puncture may become the seat of a perforation, and the direct cause of a fatal peritonitis. This is more particularly the case in operating on the bowel in cases of intestinal obstruction, as under such circumstances the walls of the bowel have become greatly attenuated from overdistention, and consequently more liable to become perforated by the needle. But the use of so many sutures, from thirty to forty as recommended, brings with it another source of danger—gangrene of the inverted margin of the bowel. The second row of sutures applied in such close proximity must materially affect the blood supply to the inverted margin of the bowel, which in some instances must terminate in gangrene. Such a result is the more likely to ensue as the inner surface of the bowel is exposed to all dangers incident to infection from the intestinal canal; in other words, an aseptic condition for one side of the wound cannot be secured, consequently the gangrene is of a septic character, which is prone to extend beyond the primary cause which produced it.

To obviate some of these dangers I experimented with a modification of Jobert's invagination suture. According to Madelung, the ingenious method of circular suturing devised by Jobert was practiced

only in four cases, and two of the patients are known to have recovered. A number of years ago, I was forced to resort to resection of a part of the small intestine in a very complicated case of ovariotomy and resorted to this method, and although the patient died forty-eight hours after the operation from causes outside of this complication, the bowel was found permeable and quite firmly united, and had the patient lived I have no doubt the result of the resection and suturing would have been satisfactory. In Jobert's method the invagination sutures must be looked upon as a source of danger, as they were made to traverse the entire thickness of the wall of the bowel, and the material used was silk. It has been claimed that in this method the invaginated portion of the bowel becomes gangrenous as in cases of invagination from pathological causes. This claim has arisen from a theoretical, and not from an experimental standpoint. In cases of invagination the intussusceptum carries with it the mesenteric vessels intact in the form of an arch, which by constriction at the neck of the intussuscipiens is prone to become strangulated, an event which is followed by œdema and inflammatory swelling of the invaginated portion, which rapidly tends to complete venous stasis and gangrene. In circular suturing by Jobert's method the intussusceptum has no vascular connection with the intussuscipiens. The vascular arch is interrupted and consequently the danger arising from venous obstruction is almost completely obviated. My experiments will show that gangrene of the invaginated portion as a rule does not occur. My modification of Jobert's method consists essentially in the use of a thin elastic rubber ring for lining the intussusceptum to prevent ectropium of the mucous membrane, to protect the mucous membrane of the bowel against injurious pressure from the suture, to keep the lumen of the bowel patent during the inflammatory stage, and to assist in maintaining coaptation of the serous surfaces, and finally the substitution of catgut for silk as invagination sutures.

My method of proceeding is as follows: The upper end of the bowel which is to become the intussusceptum is lined with a soft pliable rubber ring made of a rubber band, transformed into a ring by fastening the ends together with two catgut sutures. This ring must be the length of the intussusceptum, from one-third to half an inch; the lower margin is stitched by a continuous catgut suture to the lower end of the bowel which effectually prevents the

bulging of the mucous membrane, a condition which is always difficult to overcome in circular suturing. After the ring is fastened in its place the end of the bowel presents a tapering appearance which materially facilitates the process of invagination. Two well-prepared fine juniper catgut sutures are threaded each with two needles. The needles are passed from within outwards, transfixing the upper portion of the rubber ring and the entire thickness of the wall of the bowel and always equidistant from each other; the first suture being passed in such a manner that each needle is brought out a short distance from the mesenteric attachment, and the second suture on the opposite convex side of the bowel. During this time an assistant keeps the opposite end of the bowel compressed to prevent contraction and bulging of the mucous membrane. The needles next are passed through the peritoneal, muscular and connective tissue coats at corresponding points about one-third of an inch from the margins of the opposite end of the bowel, and when all the needles have been passed, an assistant makes equal traction on the four strings, and the operator assists the invagination by turning in the margins of the lower end evenly with a director, and by gently pushing the rubber ring completely into the intussuscipiens. The invagination accurately made, the two catgut sutures are tied only with sufficient firmness to prevent disinvagination should violent peristalsis follow the operation. This is their only function.

The invagination itself effects accurate, almost hermetical sealing of the visceral wound. The intestinal contents pass freely through the lumen of the rubber ring from above downwards, and escape from below is impossible, as the free end of the intussuscipiens secures accurate valvular closure. After a few days the rubber ring becomes detached, and by giving way of the catgut sutures is again transformed into a flat band, which readily passes off with the discharges through the bowels. The invagination sutures of catgut are gradually removed by substitution on the part of the tissues, hence the punctures in the bowel remain closed either by the catgut or by the products of local tissue-proliferation; and thus extravasation is prevented. In my first experiments I used three invagination sutures, but found by experience that two are just as efficient in making and retaining the invagination. No superficial or peritoneal sutures were used in any of the cases, sole reliance being placed upon the invagi-

nation to maintain approximation and coaptation. The mesenteric attachment, both of the intussusceptum and intussuscipiens, was separated only a few lines to enable invagination without too much narrowing of the lumen of the intussuscipiens.

Experiment 43. Dog, weight fifteen pounds. Three invagination sutures were used. The ileum was cut completely across at a point about three feet above the ileo-cæcal region. Depth of invagination one inch. For two days after operation a slight rise in temperature; no symptoms of obstruction during the whole time. Animal in good condition when killed two weeks after operation. Omentum adherent at point of operation as well as on adjacent loop of intestine. Union between intussusceptum and intussuscipiens firm, no signs of gangrene. Narrowest portion of lumen of bowel was large enough to pass the little finger to second joint. An enterolith composed of fragments of wood, bone, etc., in the centre of which the straight rubber band which had been the rubber ring, was found just above the seat of operation. No distention of the bowel above this point. Bowel considerably flexed at seat of invagination, this condition being evidently brought about by inflammatory adhesions.

Experiment 44. Dog, weight twenty pounds. Section of bowel and invagination with rubber ring the same as in the foregoing experiment. In subsequent history no mention is made of any symptom of obstruction, but for the last few weeks it was noticed that the dog began to emaciate. He died suddenly eighty-one days after the operation. Diarrhœa was a prominent symptom toward the last. No adhesions and no peritonitis. An enormous enterolith composed of all kinds of crude material, and again holding in its centre the rubber band, was found just above the invagination. Bowel at this place considerably dilated. Intussusceptum firmly adherent, a false passage admitting the tip of the little finger had been made on one side between it and the intussuscipiens. Death in this case was evidently produced by the enterolith. In this, as in the last case, the invagination was made at least an inch in length, and the collection around the detached rubber ring of the crude, indigestible material, which the dog must have eaten in large quantities, gave rise to the enterolith. The wall of the bowel surrounding the foreign body was not only dilated, but also greatly thickened. It is a well known fact that even a moderate degree of stenosis of the bowel in dogs is liable to give rise to the formation of an enterolith, as the crude material which these animals swallow becomes arrested, and by constant accretions of the same kind of material, the enterolith forms and continues to increase in size, until its presence causes catarrhal inflammation and finally intestinal obstruction.

It is quite possible that the lower end of the intussusceptum became impermeable during the inflammatory stage, and that the false passage was formed on this account by perforation on one side of the intussusceptum, an accident which was plainly traceable to too deep invagination.

Experiment 45. Dog, weight forty pounds. This experiment is interesting only from the fact that it shows that it is possible to make a mistake in

the direction of the invagination, even after the operation has determined with accuracy which is the ascending and descending end of the gut, and to show the disastrous consequences which must necessarily follow such a technical mistake. The invagination was made in the usual manner with rubber ring and three catgut sutures. The animal appeared to be quite ill the day following the operation, and on the next day the thermometer showed a rise in temperature to 104.2°F. On the third day the dog died with well marked symptoms of perforative peritonitis. Recent peritonitis with some agglutinations of intestines. Considerable quantity of sero-sanguinolent fluid in the peritoneal cavity. To my utter astonishment, I found that an ascending invagination had been made. Circular gangrene of intussusceptum and complete separation of ends was found. The rubber ring remained *in situ* still attached to the intussuscipiens by the catgut sutures, which had become somewhat softened. The invagination had decreased considerably by the traction caused by the peristalsis and by the pressure of the intestinal contents from above the obstruction, and the extensive gangrene of the bowel was undoubtedly determined to a great extent by these causes.

Experiment 46. This experiment illustrates another source of danger due to faulty technique. Medium-sized dog. Circular enterorrhaphy was done with the rubber ring two feet above the ileo-cæcal valve. In making the invagination it was noticed that the ring was too large, as it was seen that it caused too much pressure. Thinking that the parts might adapt themselves to this pressure, the bowel was replaced and the abdominal wound closed. The dog died thirty-six hours after the operation. Abdominal wound not united; omentum and intestines adherent to each other, and at point of operation. The circumscribed gangrene of the intussuscipiens was evidently entirely due to pressure on the part of the rubber ring. The intussuscipiens was much swollen, a condition which materially aggravated the pressure caused by the rubber ring. With the following experiment two new departures were inaugurated, viz.: Instead of three invagination sutures only two were used, a change which still further shortened the time for performing the operation, and Nothnagel's test was employed to determine the direction in which the invagination should be done. In all of the remaining experiments of circular enterorrhaphy which were made, only two catgut sutures were used. Until this time it was necessary to find one of the extremities of the small intestines for the purpose of determining which was the afferent and which the efferent end of the tube, so as to make the invagination in the right direction; a procedure which often required considerable time, and brought additional risk by increasing the shock of the operation and the danger of traumatic infection.

1. Nothnagel's Test.

In experimenting upon animals for the purpose of studying the functions of the intestinal canal in health and disease, Nothnagel made the discovery that when the salts of potash are brought in contact with the serous surface of the bowel, circular constriction

takes place, and when the peritoneal surface is touched with a crystal of common salt, ascending peristalsis is produced. The sodic chloride test I applied in sixteen cases, and found Nothnagel's observations corroborated in fifteen cases, by subsequent anatomical examination. In the remaining case where a wrong conclusion was drawn, the error might have been due to a faulty observation, or else the observation was not continued for a sufficient length of time. If, in the human subject, these observations could be verified, it would be of great practical importance to surgeons in operations on the intestinal canal whenever it becomes necessary to determine which is the ascending or descending part of the bowel.

Experiment 47. Dog, weight thirty pounds. Circular section of ileum and immediate enterorrhaphy by invagination with rubber ring and two catgut sutures. Intussusceptum invaginated not more that a quarter of an inch. A few days after the operation stools mixed with blood, no other unfavorable symptoms. Animal killed fourteen days after operation. Wound united firmly. A number of omental and intestinal adhesions. A small abscess in mesentery at point of operation. No obstruction of any kind. On opening the bowel the walls at site of operation were very thick, corresponding to the three intestinal coats, which had become considerably attenuated. The inner surface showed the point of junction of the intussusceptum with the intussuscipiens in the shape of a circular ring of mucous membrane. The most contracted portion was large enough to admit the little finger.

Experiment 48. Dog, weight fifteen pounds. Section of ileum and circular enterorrhaphy with rubber ring and two catgut sutures. Depth of invagination one-third of an inch. No unfavorable symptoms after operation. Animal killed after seven days. Wound completely united. Firm union of visceral wound; no gangrene of intussusceptum. Rubber ring retained *in situ* by catgut sutures, which were easily torn. Upper end of rubber ring matted with hair. No obstruction. Lumen of bowel somewhat contracted by a circular ridge of mucous membrane, which indicated the junction of the two invaginated ends of the bowel.

2. Transplantation of Omental Flap.

In almost all post-mortem examinations of specimens from operations on the intestines, I observed that the omentum was adherent over a greater or less surface at the seat of suturing. I also observed that perforations never occurred where this additional protection to the peritoneal cavity had formed. To anticipate nature in protecting the peritoneal cavity in this manner, I commenced to transplant an omental flap about an inch in width and sufficiently long to reach around the bowel, over the neck of the intussuscipiens.

where it was fastened on the mesenteric side by two catgut sutures. The flap was taken either from the margin of the omentum or from its middle, care being taken to take some portions supplied with a vessel of considerable size. Its base was left attached to the omentum; all bleeding points were carefully tied with catgut ligatures. The two catgut stitches used for its fixation were passed twice through the flap, its base and free end and the mesentery, in such a way that when tied the direction of the suture corresponded to the course of the mesenteric vessel, so that after tying they would not interfere with the vascular supply of the bowel. When the flap was taken from the middle of the omentum, the lateral halves were united with one or two catgut sutures before closing the abdominal wound.

Experiment 49. Dog, weight forty pounds. Ileum divided eighteen inches above ileo-cæcal region, and the ends united by invagination with rubber ring, and two catgut sutures. Transplantation of omental flap one inch in width around the whole circumference of the bowel over neck of intussuscipiens, fixation with two catgut sutures on mesenteric side. Invagination one-third of an inch in depth. Animal killed two weeks after operation. Abdominal wound perfectly healed. Omental flap firmly adherent to bowel over neck of intussuscipiens. Bowel at seat of operation much thickened; rubber ring gone; lumen of bowel at its most contracted point large enough for the passage of the little finger.

Experiment 50. Dog, weight twenty pounds. Complete division of ileum and immediate union of divided ends by invagination with rubber ring and two catgut sutures. Transplantation of omental flap two inches in width over the neck of the intussuscipiens. On third day stools mixed with blood. Died on the fifth day. Wound not united; omental flap firmly adherent except at a small point on the mesenteric side where a minute perforation had taken place from circumscribed gangrene of the intussusceptum. Rubber ring only loosely held by one of the sutures. Lumen in invaginated portion quite narrow, but permeable.

Experiment 51. Dog, weight fifteen pounds. Complete section of ileum and union of divided ends by invagination. The rubber ring was only one-third of an inch wide, while formerly none were used less than half an inch in width. Neck of intussuscipiens protected by an omental flap two inches wide. The dog remained perfectly well, and was killed twenty-five days after operation. Abdominal wound completely healed, covered on the inner side by adherent omentum. Rubber ring gone. Lumen of bowel at most contracted point readily admits the little finger. No signs of obstruction. Omental flap adherent throughout.

Experiment 52. Dog, weight twenty-two pounds. Division of ileum and suturing in usual manner by invagination with rubber ring and two catgut sutures; transplantation of omental flap. The dog remained perfectly well and was killed twenty-three days after operation. A number of intestinal

adhesions had produced several flexions. Point of operation four feet above the ileo-cæcal region. Omental flap firmly adherent to bowel throughout. Rubber ring gone. Lumen of bowel in invaginated portion quite large. The invaginated portion so atrophic and retracted that it appeared in the shape of a firm ring and was indicated in the interior by a circular prominence of the mucous membrane. No evidence of obstruction.

Experiment 53. Dog, weight fifteen pounds. Complete division of the ileum and reunion of ends by invagination. Transplantation of omental flap two inches in width over neck of intussuscipiens, two catgut fixation sutures. Second day after operation stools bloody. After this time all functions normal. Animal killed forty-four days after operation. Point of operation four feet below the pylorus. The invaginated portion atrophied and retracted to such an extent that the bowel at this point only presented a thickened ring with its lumen but slightly narrowed by a circular ridge of mucous membrane. Omental flap firmly adherent all around and greatly atrophied.

Remarks.—In circular enterorrhaphy, as in cases of intestinal wounds of any kind, the ideal of any operation should be to bring in continuous, uninterrupted apposition a large surface of serous membrane, without, at the same time, interfering with the vascular supply of the parts which it is intended to bring together for permanent union by cicatrization. If in employing the Czerny-Lembert sutures more than a few lines of the margins of the bowel are inverted and included between the two rows of sutures, there is great danger of causing primary traumatic stenosis by the projecting circular ring in the lumen of the bowel. The narrowing of the lumen of the bowel must be as great, if not greater, than after invagination. That the second row of sutures has often been the cause of gangrene of the inverted margin of the bowel would not be difficult to prove by many post-mortem records and specimens. By invaginating to the depth of a quarter or third of an inch, accurate coaptation is secured of the corresponding serous surfaces between the intussusceptum and intussuscipiens, which is made more secure and effective by the elastic pressure exerted by the rubber ring. This method of coaptation furnishes a large peritoneal surface of peritoneum for immediate union by cicatrization.

With perhaps one exception, all of my experiments have shown that when catgut was used for invagination sutures none of the failures were attributable to their presence. On the inner side of the bowel the rubber ring is drawn against the puncture, and would thus furnish a mechanical protection against the escape of fluids along these minute canals ; besides, the swelling of the catgut where it

becomes softened by the fluids of the tissues, would most effectually plug the punctures until a permanent plug is furnished by the granulations, which in time completely remove the catgut by substitution and close the punctures permanently by a minute cicatrix. One great advantage of the rubber ring consists in its furnishing absolute protection to the bowel against pressure by the invagination sutures during the invagination, and subsequent traction from peristaltic contraction should the latter cause tension of the sutures, an occurrence which is not likely to arise if the invagination has been properly done. A circular enterorrhaphy as described above can be done in fifteen minutes, which certainly compares very favorably with any other procedure, as far as time is concerned. In the description of a number of the specimens, it has been distinctly stated that the injurious results followed the stenosis caused by the invagination, and this might be urged as an argument against the safety and applicability of the operation.

As compared with the human subject the dog is an unfavorable animal for circular enterorrhaphy by invagination. In the first place, the walls of the bowel are much thicker in proportion to its lumen than in man, a condition which of necessity seriously affects the lumen of the intussusceptum. Again, the dogs were allowed to eat what they desired before and after the operation, and the quantity was not limited; consequently a great deal of indigestible substances, often of the coarsest kind, as straw, fragments of wood, or bone, hair, etc., found their way into the intestinal canal, and in a number of cases were arrested at the point of narrowing in the bowel, where they gave rise to the formation of an enterolith. In one instance death resulted clearly from intestinal obstruction from such a cause. In men the coats of the bowel being thinner, and the lumen correspondingly larger, invagination is done with greater ease, and the danger from stenosis could hardly come into question, as the fluid contents of the small intestines would pass readily through the rubber tube. Some of the older specimens prove that the traumatic stenosis caused by the invagination gradually diminishes by atrophy of the invaginated portions, which finally only appear as a prominent ridge of mucous membrane on the inner surface of the bowel, the remaining coats having completely or nearly disappeared by retrograde metamorphosis and absorption. In the healing of all wounds one important condition for an ideal result is rest. The

rubber ring in the intussusceptum secures this important condition for the invaginated portion, as the elastic pressure must overcome peristaltic action and secure for this segment of the bowel, as near as possible, absolute physiological rest. The danger of stenosis after invagination is greatest as soon as inflammatory swelling makes its appearance, a day or two after the operation, and the rubber ring is again in the right place to prevent any undue swelling by affording a gentle support for the invaginated portion, which cannot fail in preventing undue venous engorgement and œdema, which would otherwise follow the invagination. It serves both the purpose of a splint and an elastic bandage. After union of the bowel by invagination with a rubber ring peritoneal sutures are superfluous, as the invagination itself most effectually prevents any escape of intestinal contents by the valvular action of the invaginated portion; at the same time the serous surfaces are kept in permanent and uninterrupted contact by the elastic pressure on the part of the rubber ring.

Although the experiments have demonstrated the safety of the catgut invagination sutures in operating upon dogs, the same innocuity might not attend operations after intestinal resections for obstruction, as in such cases the coats of the bowel are almost without exception very much attenuated, and consequently the danger of extravasation along the needle punctures would be increased. Very recent trials have satisfied me that invagination after circular resection can be done with the rubber ring with facility, and probably greater safety, by dispensing with the invagination sutures and adopting the following plan: The lower end of the intussusceptum is lined with a soft rubber ring about one-quarter to one-third of an inch in width, and its lumen of sufficient size to afford free transit to the intestinal contents. The lower margin of the ring is stitched to the end of the intussusceptum by a continued fine catgut suture. The ends of the bowel are now brought in contact and fastened together with four catgut sutures which are placed equidistant from each other. Invagination is now made by gently pushing the ends of the bowel in opposite directions, being careful to push the ring sufficiently deep so that its upper margin is grasped by the neck of the intussuscipiens. A few superficial sutures are applied simply for the purpose of preventing disinvagination; the four catgut sutures act as invagination sutures, and at the same time prevent

ectropium of the mucous membrane of the lower end of the bowel during and after invagination. With proper facilities and good assistance, a circular enterorrhaphy can be made in this manner without using invagination sutures, in ten minutes; and by using not more than four retention sutures, the blood supply to the inverted portions is not impaired, and at the same time the two ends of the bowel have been joined together by a large surface of peritoneum, which is held in accurate contact for rapid union by granulation and cicatrization.

The advantages that are derived from covering a sutured intestinal wound by an omental flap are self-evident. The procedure is simply an imitation of nature's process in protecting the peritoneal cavity against perforation, and in hastening the healing of the visceral wound. An adherent omentum secures rest for the part to which it has become attached. As the omental flap becomes firmly adherent before definitive healing of the visceral wound has taken place, it furnishes additional protection, and in the event of a small perforation it guards against perforative peritonitis by mechanically preventing the entrance of pus into the peritoneal cavity. Should pus reach the omental flap after it has become firmly adherent it is not very probable that perforation would take place through the two layers of peritoneum furnished by the adherent omental flap, and the subsequent healing of the perforation of the bowel would be most likely to take place. I shall again refer to this subject under the head of "Omental Grafting."

IV. Intestinal Anastomosis.

By an intestinal anastomosis we understand a condition of the intestinal canal where on account of an obstruction or complete occlusion, the intestinal contents are directed into a segment of the bowel below the seat of obstruction or occlusion, through a fistulous opening between the bowel above and below the seat of partial or complete occlusion. The idea of establishing such a communication between the bowel above and below the seat of obstruction originated with Maisonneuve, who, without testing the new procedure first on animals, operated on two cases, but as the result in each case was fatal, he seems to have become discouraged and abandoned the operation, and never published the communication on this subject which he had in preparation. In the Surgical Society of Paris, his

proposition met with violent opposition from his contemporaries, who argued that the excluded portion of the intestine would become the seat of fæcal accumulation, which, even if the operation were a success, would subsequently destroy the life of the patient. The subject was revived in 1863 by Hacken, who under the directions of Adelmann made some experiments on dogs. For a long time the operation was completely forgotten until E. Hahn, of Berlin, very recently alluded to it again in commenting on his two cases of excision of the colon where circular enterorrhaphy could not be performed, and where an artificial anus was established. Both patients recovered from the operation, but all attempts to close the preternatural opening proved futile.

The results of my experiments have shown conclusively that the fear of accumulation of fæces in the excluded portion of the intestine, that is, the intervening portion containing the seat of obstruction and extending on each side as far as the new opening by which the anastomosis has been established, is unfounded. If this objection can be laid aside, it becomes evident that the operation of establishing intestinal anastomosis has a great future, and will soon become an established procedure in the treatment of intestinal obstruction, and as a substitute for circular suturing in some forms of injuries of the intestines, which require excision. When I first made my experiments for establishing intestinal anastomosis, I made the operation by making an incision an inch and a half to two inches in length through the convex surface of each bowel, and sutured the wounds together by Czerny-Lembert sutures the same as in making a circular enterorrhaphy. The results soon showed that the operation was attended by the same dangers as suturing after circular resection, that is, gangrene of the margins of the bowel, and perforation.

Dr. M. E. Connel, Superintendent of the Milwaukee County Hospital, suggested the use of perforated plates for making the lateral apposition, in place of suturing. A few crude experiments were made with perforated discs of lead, wood, gutta-percha, and leather, and the results soon satisfied us of the expediency and greater safety of uniting the intestines in this manner. Although the first experiments were very imperfect, and faulty in technique, almost every animal recovered. In the first experiments no needles were used. Around the oval perforation four catgut or silk sutures were tied; a slit was made in the bowel on the convex side parallel with its

axis and large enough to permit the passage of a plate about an inch in width and about two and a half inches in length. After making the incision, and introducing the plate above and below the seat of obstruction, the two wounds were brought into apposition, and the corresponding strings tied together with sufficient firmness to bring the flattened surfaces into accurate coaptation. The threads were cut short and the ends pushed inward out of sight. Experience showed that although the apposition was good, a tendency was observed on the part of the margins of the wound to evert on account of the bulging of the mucous membrane. I consequently modified the operation by arming the lateral threads with a needle with which the margin of the incision about the middle of the wound was transfixed. This proved a step in the right direction, as the lateral sutures completely prevented eversions of the margins of the wound, at the same time they fixed the plates in their position, and lastly, at once transformed the longitudinal slit into an oval foramen of sufficient size for the free passage of intestinal contents. After many trials with different kinds of materials for the plates, I came to the conclusion that decalcified or partially decalcified bone plates, preserved after the decalcification in pure alcohol, served the best purpose.

Directions for Preparing Bone Plates.

The compact layer of an ox's femur or tibia is cut with a fine saw into oval plates, one-fourth of an inch in thickness, two and one-half to three inches in length, and an inch in width. The plates are then decalcified in a ten per cent. solution of hydrochloric acid, changed every twenty-four hours until they have become sufficiently soft so that they can be bent in any direction without fracturing. After decalcification they are washed by letting water flow over them from three to six hours so as to remove the acid. The plates are then covered with porous paper and compressed between two pieces of tin until they are perfectly dry. If during the process of drying the plates are not compressed between two smooth surfaces they become distorted by warping. The hardened plates are next drilled several times in a straight line in the centre, and the openings enlarged and connected with a file, until the perforation is five-eighths of an inch in length and about one-eighth to one-sixth of an inch in width. The sharp margins of the plate and perforations are

removed with a file. With a fine drill the four perforations for the sutures are made near the margin of the oblong perforation, one at each end and one at each side. For preservation the plates are kept in absolute alcohol. When the plates are to be used they are washed in a two per cent. carbolic acid solution, and the threads or sutures attached by threading two fine sewing needles, each with a piece of aseptic silk, twenty-four inches in length, which are tied together. The threads are then fastened to the surface of the plate by another thread passing through the perforations in the shape of a loop and fastened at the back.

Instead of describing the experiments in their chronological order, I will enumerate them according to the part of the intestine operated upon, commencing with the upper portion of the intestinal tract.

I. Gastro-Enterostomy.

As gastro-enterostomy is an operation which establishes an anastomosis between the stomach and the upper portion of the intestinal canal, with exclusion of the duodenum, and sometimes a portion of the jejunum, and is performed in cases of obstruction in the pylorus or duodenum, it comes within the legitimate sphere of this article. Gastro-enterostomy, as heretofore described and performed, is an operation attended by many difficulties, and requires even in the hands of an expert an hour or more for its execution. As this operation is only done in cases greatly debilitated by disease and long suffering, anything which will simplify the technique and shorten the time must be looked upon as an improvement. An operation that can be done in ten minutes instead of an hour or two. and which furnishes even better conditions for the healing of the visceral wounds, must take the place of the more complicated procedures which so far have only been practiced in the hands of the most experienced surgeons.

Experiment 54. Dog, weight twenty-five pounds. Incision made through linea alba from xiphoid cartilage to near umbilicus. Omentum pushed to one side, and the stomach drawn forward into the wound; near the middle of its anterior surface a longitudinal incision was made, two inches in length, and a perforated gutta-percha plate, to which four medium-sized juniper catgut sutures were attached, was introduced. The lateral sutures, armed with needles, were passed through the entire thickness of the walls of the stomach, half way between the angles of the wound. A similar incision was made into

the intestine at the junction of the duodenum with the jejunum; the same kind of plate introduced, and the margins of the wound punctured by the lateral armed sutures, when the two wounds were brought *vis-a-vis* and the corresponding sutures tied. In tying the sutures, the lower lateral suture was tied first and the threads cut short; next the sutures corresponding to each angle of the wound were tied, and lastly the upper lateral. The serous surfaces of the stomach and intestine over an area corresponding to the size of the plates were brought into accurate permanent contact by the tying of the sutures. The stomach was replaced and the abdominal wound closed. The animal was allowed to eat immediately after the operation, manifested no signs of illness or pain, and was killed seven days after operation. Abdominal wound healed. Omentum adherent to its inner surface. Union between stomach and bowel firm over the entire surface of approximation. Plates detached, the one in the bowel had passed, while the other was found loose in the stomach. The new opening large enough to admit the index finger.

Experiment 55. Dog, weight fifty pounds. The operation was performed in the same manner as in the previous experiment, but great difficulty was experienced in bringing the stomach forward, as this organ was distended to its utmost with an enormous quantity of solid food. Evacuation was effected through the incision, aided by attempts of the animal to vomit, the violent contractions of the stomach forcing the food toward the opening, from which it was removed with fingers and spoon. After the stomach was emptied it was washed out with warm water. For the stomach a bone plate, only partially decalcified, was used, while the approximation plate in the bowel was fully decalcified. The four approximation sutures were of catgut. Several portions of omentum, which were soiled during the emptying of the stomach, were excised. The abdominal cavity was thoroughly irrigated with warm water before the wound was closed. The animal died the next day, and on opening the abdomen it was ascertained that the immediate cause of death was hæmorrhage, as the peritoneal cavity was filled with blood. The bleeding undoubtedly took place from the omentum, by slipping or loosening of one of the catgut ligatures.

Experiment 56. Medium-sized dog. Operation performed in the same manner with decalcified bone plates and catgut sutures. The first two days the animal had several attacks of vomiting, subsequently showed no signs of suffering. Appetite good and stools regular. Killed thirty-four days after operation. Omentum adherent to inner surface of abdominal wound. At point of operation stomach was contracted, so that the organ presented an hour-glass appearance. Interior of the organ contained a large mass of hay and fragments of bone. New opening large enough to pass index finger. Union between stomach and bowel over entire surface of approximation. Water passed into the stomach flowed through the pyloric orifice and the new opening, in a stream of equal size.

Experiment 57. Large bull-dog. Approximation of anterior surface of stomach with bowel by perforated gutta-percha plates, and four catgut sutures.

Length of visceral incisions, two inches. The day after operation animal vomited his dinner, subsequently no unfavorable symptoms. Animal killed fourteen days after operation. Abdominal wound well united. Omentum adherent to wound, duodenum, liver and at point of operation. Firm adhesions between stomach and bowel. Water passed into the stomach only passed through the pyloric orifice. On opening the stomach, it was found that the wound in the stomach and intestine had completely healed, the site of incisions being marked by a narrow firm cicatrix. The failure of obtaining an anastomotic opening between the stomach and intestine could only be attributed to one of two causes, viz.: either the perforations in the plates were too narrow, or the needles of the lateral sutures included too much tissue. Either cause would bring about approximation of the margin of the wounds and permanent closure of the opening by granulation and cicatrization.

Remarks.—All of the animals recovered, except in case of experiment 55, without any untoward symptoms, although they were allowed to eat immediately after the operation, and the diet was not selected or restricted at any time. In the fatal case death was caused from complications which had no connection with the gastro-intestinal opening. In all of the specimens examined, the mucous membrane of the stomach and intestine which had been interposed between the approximation plates, presented a healthy appearance, showing that the pressure of the plates had exercised no injurious effect on this structure. More recent experience with this operation on animals has revealed the fact that in the stomach a completely decalcified bone plate is almost entirely digested in thirty-six to forty-eight hours. It would therefore, appear advisable to use only partially decalcified bone which remains for a longer time, so that in case of delayed union the approximation would be maintained for a sufficient length of time. As the animals subjected to the operation recovered promptly, and under the most unfavorable conditions, we have every reason to believe that this operation will be attended by the same favorable results when done for pyloric or duodenal stenosis in man, where a careful preparatory and after treatment cannot fail to facilitate the operation and to improve the conditions for the formation of early adhesions and a speedy definitive healing of the wound. I have no hesitation in recommending it as a substitute for the more time-consuming and less certain operation by the tedious and difficult method of double suturing which is now generally practiced.

2. Jejuno-Ileostomy.

In this operation some form of intestinal obstruction was made; either complete, by division of the bowel and closure of both ends, or partial, by making a volvulus, invagination or flexion in the vicinity of the juncture of the jejunum with the ileum, followed by establishing a communication between the bowel above and below the obstruction. Before I made use of the perforated approximation discs, this was accomplished by making an incision an inch and a half or two inches in length through the convex surface of the bowel above and below the obstruction, and uniting the wounds by a double row of sutures. An operation of this kind usually lasted over an hour. while the rapid operation of coaptation by perforated discs seldom took more than fifteen minutes.

a. Jejuno-Ileostomy by Suturing.

Experiment 58. Large cat. Invagination of ileum into ileum in a downward direction, and fixation of intussusceptum to neck of intussuscipiens by two fine catgut sutures to prevent spontaneous reduction. Intestinal anastomosis by establishing an opening an inch in length, suturing by Czerny-Lembert method. The animal never recovered from the shock of the operation, and died in less than twenty-four hours. Length of intussusceptum two inches, which, after the removal of the sutures, could not be reached by traction, as the bowel was firmly constricted by the neck of the intussuscipiens, and recent adhesions had formed. No peritonitis; suturing found perfect.

Experiment 59. Dog, weight sixty-five pounds. Intestinal obstruction by making acute flexions in upper portion of ileum; fixation of loops of intestine by fine catgut sutures. Intestinal anastomosis between jejunum and ileum by incision and double suturing. The animal died on third day with symptoms of perforative peritonitis. On close examination, one of the superficial approximation sutures had been passed through the whole thickness of the wall of the bowel, and it was here that perforation had taken place. Recent diffuse general peritonitis.

Experiment 60. Dog, weight seventeen pounds. Descending invagination of ileum into ileum, length of intussusceptum three inches, fixation by two catgut sutures. Formation of intestinal anastomosis between the bowel above and below the invagination by incision and double suturing. Animal died on third day with symptoms of perforative peritonitis. Abdominal wound not united. Adhesions at point of operation quite firm. Diffuse general peritonitis from a perforation which had been made by a sharp fragment of bone above the new opening. Intussusceptum not gangrenous.

Experiment 61. Dog, weight twenty-three pounds. Intestinal obstruction was made by producing a volvulus in the upper part of the ileum. Restoration of continuity of intestinal canal by making a jejuno-ileostomy by lateral

apposition and double suturing. Day after operation intestinal discharges were bloody; after this time normal. Animal in perfect health when killed sixty-seven days after operation. The volvulus was found in same condition as after operation; the intestinal loop empty, atrophied and adherent to adjacent loops of intestine. Bowel above seat of obstruction and as far as the new opening empty. Intestinal tract above and below the obstruction presented no indication of the presence of an obstruction. New opening oval in shape and as large as the lumen of the bowel at that point.

Experiment 62. Large Maltese cat. Intestinal obstruction by making two flexions in ileum, about eighteen inches apart, after this portion had been cleared of its contents. Flexions made by doubling the bowel toward its convex side, and fixing it in this position by fine catgut sutures. Jejuno-ileostomy by lateral apposition and suturing. Vomiting day after operation; stools scanty the first few days, and later complete obstruction. Died nineteen days after operation. Wound completely united; no general peritonitis; flexions remained; bowel between them contained a slight amount of fæcal matter. Bowel some distance above the new opening very much dilated, pointing to obstruction above new opening. On tracing the intestinal canal from above downward, this obstruction was seen to consist in acute flexion of the bowel by firm and extensive adhesions. New opening sufficiently large to admit the tip of the index finger, around the margins of which most of the deep sutures remained attached.

Experiment 63. Large cat. Obstruction made by two flexions in the ileum, the apices of which were united by catgut sutures. Intestinal anastomosis made by a jejuno-ileostomy. For eleven days the animal remained in good condition, when symptoms of perforative peritonitis manifested themselves, and death ensued two days later. External portion of wound not united. Numerous omental and intestinal adhesions. Flexions retained and their apices adherent to each other by firm band of adhesion. Excluded portions above and below the obstruction empty. Two small perforations at point of suturing on anterior surface of bowel; remaining portion of wound firmly united. New opening sufficiently large to admit tip of index finger. Death from perforative peritonitis.

Experiment 64. Large, Newfoundland dog. Descending invagination of ileum into ileum to the extent of six inches; fixation of intussusceptum by two catgut sutures. Permeability of intestinal canal restored by making a jejuno-ileostomy; wounds united by a double row of sutures. Intestinal discharges normal throughout. No rise in temperature. General condition as good as before operation, when killed on the twentieth day. Abdominal wound completely united; no peritonitis; omentum adherent at site of operation. Invagination had reduced itself, and its location was marked by an acute flexion caused by extensive adhesions. No accumulation of intestinal contents in excluded portions. The new opening at least two inches in length; a few of the deep sutures remained attached to its margins. This opening was partially obstructed by a mass of hair and fragments of bone. On passing a stream of water from above downward, the fluid passed through an opening in

the centre of this mass into the lower portion of the ileum, but not through the portion that was invaginated. After this mass was removed, the fluid was found to pass through the portion that was invaginated, as well as through the new opening.

The many failures which attended jejuno-ileostomy and ileo-ileostomy by lateral apposition and suturing, led to the use of perforated approximation discs. A great contrast was observed in the animals operated upon by these two methods. The operation by suturing required usually more than an hour, and almost all of the animals showed more or less symptoms of shock after its completion, and not a few succumbed to its immediate effects; while the operation by approximation plates could always be finished within twenty minutes, consequently the animals never suffered seriously from the immediate effects of the operation. The first experiments were made somewhat carelessly and with crude material, and yet it was observed that the healing process progressed more favorably and was accomplished in a shorter time than after suturing. The approximation discs brought into uninterrupted contact large serous surfaces without impairing the vascular supply; at the same time they secured for the parts destined to become united an essential condition for rapid wound healing—rest—by serving the useful purpose of splints.

Experiment 65. Dog, weight fifteen pounds. Ileum was completely divided at its junction with the jejunum and both ends of the bowel closed by invagination, and three stitches of the continued suture. An incision was made on convex side of bowel about two inches from the closed ends, and a heavy perforated lead plate to which six catgut sutures were fastened around the oval perforation, was introduced into the lumen of the bowel of each closed end, all of the catgut sutures being brought out through the incision. The two wounds were brought opposite each other and the six sutures tied. The serous surfaces of the two intestines over a surface corresponding to the size of the lead discs were thus brought into accurate apposition. The sutures were cut short and the ends buried as deeply as possible. The condition of the animal remained excellent until the time of killing, seventy-five days after operation. Omentum adherent to wound; large intestines distended with normal fæces. Bowel above and below point of operation normal in size and structure. New opening between ileum and jejunum large enough to admit the little finger to second joint. Bowels firmly united by a broad surface. Above the communicating opening a double flexion of the bowel was found which apparently had done no harm.

Experiment 66. Dog, weight eighteen pounds. Operation done in the same manner as in the last experiment, only that instead of lead the discs were made of sole leather, and the sutures used were linen in place of catgut.

For a few days the temperature was higher than normal and appetite diminished. After fourth day the animal appeared to be in excellent condition and remained so for three weeks, when the appetite failed and occasional attacks of vomiting set in. The symptoms remained more or less prominent until the time of killing, thirty-nine days after operation. Omentum adherent to abdominal wound ; extensive intestinal adhesions at site of operation ; union between intestines perfect. On incising the bowel it was found that the plates had sloughed through, and had passed along the distal portion of the bowel, leaving an opening the size of the plates, the margins of which had almost completely cicatrized. The two leather plates, still held together by the linen sutures, were found three feet lower down in the ileum, where they had become embedded in a mass of hair, straw and fæcal matter, and quite firmly impacted, causing complete obstruction of the bowel. The intestine above the seat of obstruction was enormously dilated, while below the seat of impaction it was empty and contracted. Large intestines likewise empty and contracted. The cause of the illness was evidently due to intestinal obstruction produced by the impaction of the large enterolith, in the center of which the leather discs were found.

Experiment 67. Dog, weight ten pounds. In this instance the bowel was divided near the junction of the jejunum with the ileum, both ends closed, and its continuity established by incising the convex surface of both ends, and approximating the wounds by two perforated bone plates tied together by silk ligatures. The animal died fourteen days after operation. During the last few days symptoms of intestinal obstruction were present. Abdominal wound completely united. Numerous intestinal adhesions at site of operation. Bone plates still *in situ* and firmly fixed. On proximal side, perforation of bone plates completely closed by hair and fragments of bone, giving rise to complete intestinal obstruction. The bowel above this point was greatly dilated, while on distal side it was empty and contracted. Firm adhesions between the two intestinal surfaces included by the bone plates. Intestinal obstruction by a mechanical arrest of portion of the intestinal contents above the proximal plate had caused death before a more efficient communication could be established by sloughing through of the bone plates.

Experiment 68. Dog, weight thirty pounds. Ileo-ileostomy by dividing the ileum near its centre, closing both sides, and after incising both ends on convex surface, bringing wounds in apposition by perforated plates of cross-grained walnut wood, which were tied together with silk sutures. The dog remained in perfect health and was killed eighteen days after operation. External wound completely united. Plates had become detached, leaving a communicating opening two inches in length. Blind ends of bowel empty; no trace of plates could be found.

Experiment 69. Dog, weight twenty-four pounds. Double ileo-ileostomy. Ileum divided transversely five inches above ileo-cæcal region, and both ends closed by invagination and three stitches of the continued suture. Lower and upper end of bowel were again brought into communication by incision on convex side, and lateral apposition of wounds by means of perforated

approximation plates of decalcified bone, hardened in alcohol. The plates were fastened together by four silk sutures, all of the threads being brought out of the incision, tied and cut short. Above this point a loop of the ileum was made by bringing the convex surfaces into apposition after incision at two points, and introducing perforated gutta-percha plates, which were retained in place by four silk sutures. No fever or symptoms of obstruction followed the operation. Animal killed thirteen days later. External wound firmly united. No evidences of peritonitis or intestinal obstruction. First operation left a communicating opening large enough to admit the little finger in one of its margins. The silk ligatures which had become detached from the plates had embedded themselves. The decalcified bone plates had disappeared and no trace of them could be found in any portion of the intestinal canal lower down. The second operation was thirty inches higher up. Gutta-percha plates remained *in situ*, although somewhat loosened by the gradual disappearance of the intervening tissues by pressure atrophy. Adhesions between the two surfaces of the bowel firm, and extending a little beyond the line of approximation. The perforation in the proximal plate almost completely closed by an accumulation of hair. The entire ileum normal in size and appearance.

Experiment 70. Dog, weight fifty-four pounds. Transverse section of ileum thirty inches above ileo-cæcal region and closure of both ends in the usual manner. The two closed ends were overlapped four inches and brought into communication by two longitudinal openings, which were approximated by being buttoned together with a shuttle-shaped button, nearly one and a half inches in length, the sides being lead plates and the shaft a rubber tube through which the anastomosis was established at once. As the margins of the intestinal wounds showed a tendency to evert, a fine catgut suture was inserted on each side embracing only the peritoneal coat. Only for two or three days after the operation did the dog not appear to be well. Killed twenty-three days after operation. Omentum adherent to abdominal wound which was firmly united. Omental adhesions to intestine at site of operation. Intestinal anastomosis thirty inches above the ileo-cæcal valve. Proximal blind end of bowel five inches in length adherent to distal end, considerably dilated and contained fragments of bone and other crude substances. Approximation button *in situ* and quite firmly fixed. A fragment of bone partly filled the lumen of the rubber tube. Coaptated peritoneal surfaces firmly adherent. The obstruction of the communicating tube had given rise to dilatation of the bowel above the point to twice its natural size, while below the seat of partial obstruction the intestine appeared empty and contracted.

Experiment 71. Small dog. In this experiment the ileo-ileostomy was made by lateral apposition by perforated approximation plates of partially decalcified bone tied together by four catgut sutures. The lateral sutures were passed through the margins of the wound near its border, a modification of the usual procedure, which not only fixed the plates firmly in their places, but also prevented ectropium of the mucous membrane, and ensured free patency of the new opening by retracting the margins of the wound, so that the longi-

tudinal slit was at once transformed into an oval shape. The animal showed no unfavorable symptoms and was killed twenty-nine days after operation. Dog well nourished. External wound united. Omentum adherent to wound and intestines. The proximal blind end of bowel contained one of the bone plates which showed signs of softening and disintegration. The bone plate in the distal end had been passed with fæces previously. The new opening perfect and sufficiently large to equal in size the lumen of the bowel.

Experiment 72. Dog, weight twelve pounds. Made ileo-ileostomy the same as in the last experiment, using decalcified perforated bone plates, which were tied together with four catgut sutures, the lateral ones being passed through the margins of the wound. An omental flap was used to cover the sides of the bowel where approximation had been made. This flap was retained by two fine catgut sutures. No unfavorable symptoms. Animal killed twenty-three days after operation. Omentum adherent to distal blind end. Omental flap in position and firmly adherent. Site of operation fourteen inches above ileo-cæcal region. Both bone plates had disappeared and no trace of them could be found. Some hair had collected in the blind proximal end. New opening large enough to admit the index finger.

Remarks. — Jejuno-ileostomy or ileo-ileostomy by internal apposition with decalcified perforated bone plates in cases of complete obstruction of the bowel artificially produced, is an operation almost devoid of danger. Partially or completely decalcified bone plates hardened in alcohol remain firm for a sufficient length of time to answer the purpose of retentive measures, until firm adhesions have formed between the serous surfaces held by them in approximation. Until it was ascertained by experiment that the plates would undergo softening and disintegration in the course of a few days, catgut sutures were used to hold them in place with the expectation that the plates would become detached and escape with the intestinal contents as soon as the sutures would give way. Experience, however, has shown that aseptic silk threads are preferable to catgut, as they can be tied with greater accuracy and the knots will never become loosened, while the approximation discs disppear completely by softening and disintegration in a few days. Approximation plates of inabsorbable material as lead, wood, leather, bone, and gutta-percha, fastened together by silk or linen sutures, remain *in situ* until the interposed tissues disappear by pressure atrophy, and the opening that results corresponds in size to the dimensions of the plates. In the first experiments the plates were tied together by six sutures, but it was found that four sutures answered the same purpose. As a rule the plates were about two

and a half inches in length, and their width corresponded to one-third of the circumference of the bowel. The greatest advantage to be found in the method of restoring the continuity of the intestinal canal by lateral apposition by approximation discs, consists in the fact that the point of contact is always made on the convex surface of the intestines, so that the means employed to secure coaptation do not interfere with the blood supply from the mesenteric vessels. As this method requires much less time than any form of circular enterorrhaphy, and has been followed almost without exception by recovery, it recommends itself strongly as a substitute for the latter procedure in many cases where loss of time constitutes an important factor in the issue of the case, or where from other causes circular suturing appears impossible or impracticable.

3. Ileo-Colostomy.

As the ileo-cæcal region is frequently the seat of intestinal obstruction, it becomes desirable to devise some definite plan of operative treatment in cases where the cause of obstruction is not amenable to removal, with a view of establishing the continuity of the intestinal canal, thus avoiding the necessity of resorting to the formation of an artificial anus. To accomplish this object two distinct methods were followed: 1. Division of the ileum with closure of distal and implantation of proximal end into colon. 2. Division of ileum, closure of both ends and lateral apposition of proximal end with colon, and the formation of an intestinal anastomosis by suturing or approximation discs.

a. Ileo-Colostomy by Implantation.

Experiment 73. Dog, weight thirty-eight pounds. Intestinal anastomosis by implantation of ileum into colon. The ileum was divided transversely just above the ileo-cæcal region, and the distal end closed by invagination and three stitches of the continued suture, and dropped back into the abdominal cavity. A longitudinal incision, in size corresponding to the lumen of the ileum, was made in the ascending colon at a point directly opposite the mesentric attachment, and the proximal end of the ileum was then fixed in this opening by Czerny-Lembert sutures. Only slight febrile reaction followed the operation. The appetite remained good and the discharges from the bowels were normal. The animal was in excellent condition when killed, thirty-three days after operation. Few circumscribed omental adhesions to abdominal wound, which was completely closed. Peripheral portion of ileum presented a conical appearance, and was found adherent to, and of the same length as the appendix vermiformis. Implantation had been done about the

middle of the colon. Union at point of suturing perfect, apparently no interruption of continuity of peritoneal surface. The new opening into colon a little smaller than the lumen of the ileum. Around the margins of this opening, which somewhat resembled the ileo-cæcal valve, six of the deep silk sutures remained attached. Above the new opening the colon and cæcum were found empty and somewhat atrophic. Lower portion of the ileum and colon below the new opening appeared normal in size and structure.

Remarks.—In the remaining experiments the implantation was made by lining the proximal end of the ileum with a narrow flexible rubber ring, which was retained in place by a continued catgut suture, embracing the free margin of the bowel and the lower margin of the rubber ring. The implantation was made by two catgut sutures, threaded each by two needles and passed at opposite points from within outwards through the upper margin of the ring and the entire thickness of the bowel, while the needles were only passed through the serous and muscular coats of the colon. After both sutures were in place gentle traction upon all of the ends brought the end of the ileum into the incision in the colon, and the walls of the colon were drawn over the end of the ileum to the points where the needles emerged from the ileum, making really a limited invagination. When in proper position, the serous surfaces of the colon and ileum over a surface corresponding to the width of the rubber ring were in accurate coaptation, after the two sutures were tied. Only in exceptional cases was it found necessary to apply one or two additional superficial coaptation sutures. As in circular enterorrhaphy, so in these cases, the elastic pressure on the part of the rubber ring rendered material assistance in maintaining accurate coaptation, while at the same time it secured rest for the sutured parts, and kept the new opening freely patent for the escape of intestinal contents into the colon. This operation did not require one-fourth of the time consumed in making an implantation by Czerny-Lembert sutures.

Experiment 74. Dog, weight fifty pounds. Division of ileum eight inches above ileo-cæcal region, distal end closed by invagination, and three stitches of the continued suture. Proximal end lined with rubber ring and implanted into incision of ascending colon by two catgut invagination sutures. The dog did not appear to do well after the operation, and died on the fifth day. Abdóminal wound not united. Partial separation of implanted bowel and diffuse septic peritonitis from perforation.

Experiment 75. Dog, weight thirty-five pounds. Ileum divided twelve inches above ileo-cæcal region, distal end closed and proximal end lined with flexible rubber ring and implanted into an incision in the transverse colon,

and retained by two invagination sutures of catgut. An omental flap an inch and a half in width was placed over the junction of the two intestines and fixed in its place by two catgut sutures. No unfavorable symptoms after operation. Animal when killed eighteen days later, in excellent condition. Omentum adherent to abdominal wound which was firmly united. Omental flap adherent all round. Colon above new opening ten inches in length, completely empty, contracted and atrophic. New opening oval in outline and as large as the lumen of the ileum.

Experiment 76. Dog, weight sixteen pounds. Division of ileum, closure of distal end and implantation of proximal into an incision of the colon by rubber ring and two invagination sutures of catgut. As the inverted portions of the colon showed a tendency to evert, two additional retaining sutures of fine catgut were used, which secured perfect coaptation throughout. An omental flap was laid over the junction of the intestines and fixed in its place by one catgut suture. The dog remained in good condition, appetite unimpaired, and discharges from bowels normal. Killed thirteen days after operation. Abdominal wound firmly united. Omentum adherent to wound. A number of adhesions between coils of intestine. Ileum somewhat dilated above the new opening. Omental flap in place and adherent. Union between ileum and colon perfect. A long, sharp fragment of bone was found lodged just above the new opening, the lower end partially occluding its lumen. The dilatation of the lower portion of the ileum was evidently due to partial obstruction from the presence of the foreign body in the new opening.

Experiment 77. Dog, medium size. Section of ileum two feet above the ileo-cæcal region, closure of distal end in the usual manner, implantation of proximal end into colon by rubber ring and two invagination sutures of catgut. No omental flap. Animal remained well and was killed forty-three days after operation. Omentum adherent to abdominal wound. Distal end of ileum conical in shape, the extremity presenting a cup-shaped depression, which was filled with cicatricial material. Omentum adherent at ileo-cæcal region and at site of operation. Union between the bowels perfect and their serous surfaces appeared to be continuous over the line of junction. The new opening from the colon admitted the little finger, and was surrounded by a prominent ridge of mucous membrane, which resembled the ileo-cæcal valve.

Experiment 78. Dog, weight fourteen pounds. Division of ileum a few inches above ileo-cæcal valve, distal end closed by invagination, and three stitches of continued suture. Implantation of proximal end into colon by rubber ring and two catgut invagination sutures. Over the junction of the two intestines an omental flap was placed which was retained by a catgut suture. The animal showed no unfavorable symptoms and was killed twenty-three days after operation. Omental flap retained and firmly adherent throughout. Point of implantation three inches above cæcum; union between the two intestines firm throughout. New opening corresponded in size to the lumen of the ileum, and was surrounded by a prominent ridge of mucous membrane which appeared to be derived from the invaginated portion of the ileum.

Experiment 79. Ileum divided a few inches above ileo-cæcal region, and after closure of the distal, the proximal end was implanted into the colon in the usual manner by a rubber ring and two invagination sutures of catgut. Animal died on third day after operation. Wound partially united; a considerable quantity of sero-sanguinolent fluid in the abdominal cavity. Ileum almost completely separated from colon, and the portion which had been invaginated showed signs of gangrene. Rubber ring had disappeared; death from perforative peritonitis. In this case we have reason to believe that the rubber ring which was used was too large, and that the gangrene and separation was due to injurious pressure.

b. Ileo-Colostomy by Lateral Apposition.

Anastomosis by this method was made after producing an intestinal obstruction of some kind at or near the ileo-cæcal region, and then by bringing the ileum above the seat of obstruction in communication with the colon below the point of obstruction, by making an incision an inch and a half to two inches in length in both intestines at a point opposite the mesenteric attachments, and uniting the wounds either by a double row of sutures or perforated decalcified bone discs. The first experiments were all made by suturing but, as in circular enterorrhaphy, it was found by experience that perforation not infrequently occurred along the track of one of the sutures, in some instances several days after the operation, at a time when union had taken place by firm adhesions. These unfavorable results led to the use of the approximation discs.

Experiment 80. Dog, weight twenty-five pounds. The ileum was withdrawn from the abdomen through an incision in the linea alba, and having emptied a loop of its contents, acute flexion was made just above the ileo-cæcal region by approximating the serous surfaces of the convex side for a inch and a half by five catgut sutures. Two longitudinal incisions of equal size were made, one in the ileum six inches above the flexion, and the other in the ascending colon three inches above the cæcum. The visceral wounds were carefully united by Czerny-Lembert sutures, using silk for the deep interrupted sutures, and fine catgut for the superficial continued sutures. No untoward symptoms were observed after the operation; appetite remained unimpaired, and fæcal discharges were normal. The dog was killed thirty-seven days after operation. Animal well nourished. No evidences of peritonitis. Bowel above point of obstruction nearly empty, and somewhat contracted as far as the new opening. Flexion permeable to a stream of water. Slight omental adhesions to bowel at site of operation; union firm throughout. Lumina of non-excluded portion of bowel normal in size above and below the flexion. Serous surfaces at point of junction appeared perfect and continuous. On slitting open the colon opposite the new opening, its outlines were seen to be marked by a prominent ridge of mucous membrane to which a number of the deep sutures

remained attached. The opening was large enough to admit the tip of the middle finger. The excluded portion of the colon and the cæcum were somewhat contracted and atrophic, and contained only a very small quantity of fæcal matter.

Experiment 81. Medium-sized cat. About two inches of the ileum were invaginated into the colon through the ileo-cæcal valve, and the intussusceptum stitched to the neck of the intussuscipiens by two fine catgut sutures. Continuity of the intestinal canal restored by incising the ileum above the obstruction, and the ascending colon below the free extremity of the intussusceptum, and uniting the wounds by a double row of sutures. The invagination caused no serious disturbance, and the animal remained in good health and was in excellent condition at the time of killing, one-hundred and sixty-two days after operation. A number of adhesions between the folds of the intestines near the site of operation. At point of juncture of the two intestines the peritoneal surface presented a glistening and continuous surface. New opening an inch and a half in length, oval in outline and located five inches above the ileo-cæcal region. Two inches below the opening the invagination remained in the shape of a circular thickening of the bowel with a narrowing of its lumen to more than one-half of its normal size. A close inspection of the specimen showed that no gangrene had occurred, but that the intussusceptum had undergone atrophy. A stream of water passing along the ileum in a downward direction escaped through the invaginated portion and through the new opening, the stream from the latter being at least three times larger than the one through the intussusceptum. Excluded portion of ileum and colon empty and very much atrophied and contracted. Below the new opening the colon and rectum contained normal fæces in considerable quantity.

Experiment 82. Young cat. Ileo-cæcal invagination; length of intussusceptum four inches. In order to prevent spontaneous disinvagination the bowel was fixed in its position by two fine catgut sutures. Ileo-colostomy below the lower end of the intussusceptum by lateral apposition and suturing. Animal died on the fourth day after operation. Abdominal wound united. Diffuse peritonitis from perforation at site of suturing. Length of intussusceptum reduced from four inches to two inches and a half. It was found impossible to effect reduction by traction on account of firm adhesions at neck of intussuscipiens. No gangrene.

Experiment 83. Adult, large dog. Intestinal obstruction was produced by making two sharp flexions near the ileo-cæcal region by folding the bowel on its side and fixing it in this position by fine catgut sutures; the apices of the flexions were sutured together so as to render the obstruction more complete. Intestinal anastomosis was established by lateral apposition and suturing. Physical condition of dog remained good throughout; appetite and evacuations normal. Killed thirty-one days after operation. No peritonitis; a number of omental adhesions at point of operation. Flexions quite sharp, rendering the bowel nearly, if not completely, impermeable at this point. Perfect union between bowels, with some thickening of their walls by inflammatory exudation. New opening oval in shape, an inch and a half in length,

a few of the deep sutures still remaining attached to its margins. Excluded portion of bowel empty and somewhat atrophic.

Experiment 84. Dog, weight thirteen pounds. Obstruction of the bowels made by an acute flexion four inches above the ileo-cæcal region, retained by four catgut sutures. Intestinal anastomosis by an opening an inch and a half in length, which brought into communication the ileum above the obstruction and the descending colon. The animal showed no untoward symptoms, and was killed forty-one days after operation. A number of intestinal folds agglutinated by adhesions; no evidences of diffuse peritonitis. Where the flexion had been made the loop of intestine was connected by a broad band of adhesion which gave to the bowel a horse-shoe shaped appearance. Intestine below the seat of flexion contained a small amount of hardened fæces. Colon and cæcum above the new opening nearly empty and greatly contracted. Line of suturing somewhat thickened. New opening oval in outline and about an inch in length, surrounded by a corrugated elevation of mucous membrane. A stream of water passed through the bowel from above downward readily escaped through the new opening, while only a small stream could be forced through the flexion.

Experiment 85. Dog, weight twenty-seven pounds. A volvulus was made six inches above the ileo-cæcal region by rotating an empty loop of the intestine once around its axis, and fixing it in this position by three catgut sutures. Intestinal anastomosis between the ileum above the volvulus and the descending colon by lateral apposition and suturing. For four days after the operation the evacuations from the bowels contained blood; after this time the stools were normal. Dog in excellent condition when killed thirty-one days after operation. No signs of diffuse peritonitis. The portion of bowel which constituted the volvulus adherent, contracted and empty. Water could be readily forced through this part of the bowel. Cæcum and colon above new opening empty and contracted. Size of new opening larger than the lumen of the ileum, its margins surrounded by a prominent ridge of mucous membrane to which a few of the deep sutures still remained attached. In this experiment nearly the entire colon was excluded, consequently the fæcal discharges were quite frequent and fluid or semi-fluid in consistence.

Experiment 86. Dog, weight seventeen pounds. Two inches of the ileum were invaginated into the cæcum. Ileo-colostomy by uniting the ileum with the transverse colon by suturing. The animal appeared quite ill after the operation and died on the fifth day after having manifested well-marked symptoms of perforative peritonitis. Abdominal wound not united. Only partial union between the intestines at point of junction. Diffuse septic peritonitis from perforation.

Remarks.—In at least two experiments which are not here reported, the animals died of shock a few hours after operation. In a number of other experiments the operation was followed by more or less shock, but the animals, without receiving any special treatment, rallied after six to twelve hours. The symptoms referable to

the immediate effects of the operation were due to the length of time required in applying a double row of sutures in uniting the visceral wounds, a step in the operation which always required from thirty minutes to an hour. These experiments only corroborate the statement previously made that the excluded portion of the intestinal canal, including the obstruction, does not become the seat of fæcal accumulation, but undergoes atrophy after free intestinal anastomosis has been established between the intestine above and below the seat of obstruction. Experiments Nos. 70 and 71 furnish most striking proof that the danger of gangrene in cases of invagination is greatly diminished by establishing an early intestinal anastomosis, as when this is done the violent peristalsis is promptly arrested by furnishing a new outlet to the intestinal contents ; at the same time, the serious consequences resulting from pressure and distention above the obstruction are likewise promptly averted. In cases of intestinal anastomosis where nearly the entire colon has been excluded, the fluid contents of the small intestines reach the rectum at once, and cause frequent fluid fæcal discharges, an occurrence which does not appear to impair the general health of the animal. The new opening should be made of adequate size, so that its lumen will at least correspond to the lumen of the bowel above the obstruction.

c. Ileo-Colostomy by Perforated Approximation Discs.

Experiment 87. Dog, weight twenty pounds. The ileum was completely divided three inches above the ileo-cæcal region, both ends closed by invagination and three stitches of the continued suture. A communication was established between the proximal extremity and the colon, by making an incision into the ileum on convex side near the closed end and introducing through this opening a perforated decalcified bone plate. A similar opening was made into the ascending colon opposite its mesenteric attachment, through which a perforated plate of wood was introduced. To each plate were tied four catgut sutures. The lateral sutures were passed through the margins of the wound. After the plates and sutures were in place the wounds were brought in contact and the four sutures tied, which coaptated the serous surfaces of both bowels over an area corresponding to the size of the plates. The animal remained apparently well for two days, when symptoms of peritonitis set in and death occurred five days after operation. Diffuse peritonitis. Union at point of operation incomplete, which resulted in a perforation. Discs had disappeared. As the catgut sutures were quite fine it is more than probable that partial separation of the plates occurred before adhesions had taken place between the serous surfaces of the coaptated bowels, which resulted in perforation and death from diffuse septic peritonitis.

Experiment 88. Dog, weight fifteen pounds. Invagination of colon into colon to the extent of two inches. Intestinal anastomosis by making an ileo-colostomy by lateral apposition of the ileum to colon below invagination, using perforated hard rubber plates which were tied together by four catgut sutures, the lateral sutures being passed through the margins of the wound. After tying the sutures it was found that at one point the margins of the wound showed a tendency to evert, consequently a fine catgut suture was passed through the peritoneum only and tied. The animal did not appear bright the day after the operation, but subsequently showed no signs of suffering; killed twenty-four days after operation. Abdominal wound firmly united. Omentum adherent to wound and at point of operation. The invagination was partially reduced. The bowel at this point was curved in the shape of a horse-shoe, but permeable to a stream of water. Excluded portion of colon tortuous and atrophic. Cæcum contained a small quantity of fluid fæces. Plates could not be found. New opening sufficiently large for free passage of intestinal contents.

Experiment 89. Dog, weight fifteen pounds. Ileum divided transversely fifteen inches above the ileo-cæcal region; both ends closed in the usual manner. Ileum and colon approximated by decalcified perforated bone plates which were tied together by four catgut sutures, the lateral ones transfixing the margins of the wound. On the second day the evacuation from the bowels contained traces of blood. Animal killed eighteen days after operation. Abdominal wound completely healed. Omentum adherent to wound. Numerous adhesions between the intestinal folds. Proximal blind end of ileum had been changed into a pouch-like form and contained a mass of hair and fragments of bone. One very sharp spiculum of bone had nearly perforated the intestine. New opening corresponded in size to the lumen of the ileum.

Remarks.—The operations of lateral apposition of ileum to colon by perforated approximation discs, have shown that it is unsafe to rely upon catgut as a suturing material, as when fine catgut is used coaptation is not maintained for a sufficient length of time for adhesions to take place, and coarse catgut when tied interferes with accurate approximation, as the knots after tying mechanically separate the serous surfaces. It is advisable to use removable plates and to tie with silk. The results of ileo-colostomy made by approximation discs have not been as favorable as after jejuno-ileostomy or ileo-ileostomy, and in repeating the operation on man it would be indicated, after bringing the intestines in apposition by tying the four sutures, to apply a number of superficial sutures for the purpose of still further guarding against the escape of gas or fluid contents into the peritoneal cavity. The plates when properly fixed in their places and tied together with sufficient firmness, not only

coaptate an extensive area of serous surfaces, but they at the same time secure perfect rest for the parts which it is intended to unite, until firm adhesions have formed.

4. Ileo-Rectostomy.

In cases of intestinal obstruction due to inoperable conditions low down in the colon, it becomes necessary to establish an intestinal anastomosis between the ileum and the rectum, in order to avert the necessity of making an artificial anus; in other words, to make an ileo-rectostomy. The operation can be made in the same way as establishing a communication between the ileum and the colon by lateral implantation, by lateral apposition and double suturing, or by lateral apposition by perforated decalcified bone plates. The operation is, however, more difficult because the rectum is not as accessible as the colon, and from the greater vascularity of the gut, the incision is more liable to give rise to troublesome hæmorrhage. While the slight hæmorrhage from an incision into the small intestines and the colon is usually promptly arrested by suturing, or compression by the approximation discs, the bleeding from a wound of the upper portion of the rectum not infrequently requires the application of one or more catgut ligatures before it is safe to unite the wounds. During the operation traction must be made upon the rectum in an upward direction so as to lift the upper portion of the bowel out of the pelvis. In both of the experiments described below, the wounds were united by Czerny-Lembert sutures.

Experiment 90. Dog, weight ninety pounds. Invagination of colon into colon for two inches and suturing of intussusceptum to neck of intussuscipiens by four fine silk sutures to prevent spontaneous disinvagination. Ileum incised in a parallel direction for an inch and a half on convex side, and this wound united with a similar incision in the rectum on its anterior surface by a double row of sutures. For the purpose of immobilizing the sutured intestines an additional fine catgut suture was applied above and below the place of suturing, embracing only the peritoneal and muscular coats of the intestines. On the third, fourth, and fifth days the fæcal discharges contained blood and mucus. On the sixth day the abdominal wound partially opened, and a considerable quantity of sero-purulent fluid escaped. Death seven days after operation. Abdominal wound not united. Diffuse purulent peritonitis. Numerous intestinal adhesions. Invagination retained; adhesions between the intussusceptum and intussuscipiens; no gangrene; perforation at point of operation.

Experiment 91. Cat, weight seven pounds. Ileo-rectostomy by lateral implantation. The ileum was cut across transversely an inch above the ileo-

cæcal valve, and the distal end closed by invagination and three stitches of the continued suture. The proximal end was transplanted into a longitudinal incision on the anterior surface of the upper portion of the rectum by Czerny-Lembert sutures. With the exception of an occasional slight rise in temperature no serious disturbances were observed during the progress of the case. The evacuation of the small intestines directly into the rectum appeared to increase the peristaltic action of the rectum, as the fæcal discharges were fluid and frequent. Animal killed twenty days after operation. Abdominal wound completely united. No peritonitis. A few folds of the small intestines and the omentum adherent to the wound. Insertion of ileum into rectum in an oblique direction; union at point of junction complete throughout; intestinal coats at this point somewhat thickened. Peritoneal surface smooth and continuous from one bowel to the other. New ileo-rectal opening corresponded in size to the lumen of the ileum; margins of this opening consisted of a ridge of mucous membrane to which a row of the deep sutures remained attached. Excluded portion of large intestine empty and contracted. Rectum contained a small quantity of fluid fæces.

5. Colo-Rectostomy.

Among the many possibilities in the operative treatment of intestinal obstruction, a condition might be met with where the seat of obstruction is located low down in the colon, perhaps in the sigmoid flexure, and where it might be impossible or impracticable to remove the cause of obstruction, and where it becomes necessary to restore the continuity of the intestinal canal by establishing a communication between the permeable portion of the colon and the rectum. Such an anastomosis can be made, as in ileo-colostomy, by lateral implantation, lateral apposition by perforated approximation plates, or by double suturing. For want of time only one experiment was made, and although the animal died from the immediate effects of the operation, the local conditions at the site of operation found after death showed that colo-rectostomy in selected cases is not only a justifiable and feasible operation, but whenever it can be done, that it is always preferable to the formation of an artificial anus. As the operation by lateral apposition requires much less time than lateral implantation, it should be preferred to the latter procedure, and should be done by perforated approximation discs and a few superficial sutures.

Experiment 92. Medium-sized cat. Incision through the linea alba; colon cut transversely in the middle third and the distal portion, and the rectum cleared of its contents by injecting a stream of warm water from the cut end downward, a procedure which could only be well accomplished after forcible

dilatation of the sphincter ani muscles. The distal end was closed in the usual manner. The rectum was drawn upward and an incision made into its anterior wall large enough to correspond with the lumen of the colon. Into this opening the proximal end of the colon was implanted by two rows of sutures. During the latter part of the operation, which lasted over an hour, the animal was seized by convulsions which continued for several hours, and finally subsided nnder the administration of whisky given hypodermically. The symptoms of shock, however, continued and death occurred thirty-six hours after operation. Nnmerous omental adhesions; closed end of bowel congested; peritoneal surfaces adherent; colon and rectum at point of implantation adherent.

Remarks.—In cases where the obstruction is located some distance from the rectum, where it would be impossible to approximate the permeable portion of the colon with the rectum, the entire colon must be excluded and the continuity of the intestinal canal restored by ileo-colostomy or ileo-rectostomy. In all cases of intestinal anastomosis where the communication is made in the lower portion of the colon or the rectum, the sphincters of the anus should be rendered temporarily incompetent by stretching, for the purpose of guarding against over-distention of this part of the bowel during the time required for the healing process between the united intestines.

V. Adhesion Experiments.

In works on abdominal surgery we invariably meet with the assertion that serous surfaces brought into apposition by suturing unite after a few hours. Isolated experiments and the results of post-mortem examinations have given rise to the general belief that serous surfaces so united will become firmly adherent in a very short time; but the question concerning the exact time for adhesion to take place, and for the definitive healing to be complete, can only be determined by experiments made for this special purpose. The following experiments were made with a view of ascertaining the exact time which is requisite for adhesions and definitive healing between approximated serous surfaces to take place, and likewise to study the effects of local conditions which would hasten or retard these processes. It is quite important to make a distinction between the terms "adhesion" and "healing." Adhesion precedes the process of definitive healing, but implies simply the presence of an adhesive or cement substance between the serous surfaces, which mechanically agglutinates the parts; while definitive healing includes

all the processes which take place during cicatrization. In intestinal surgery this distinction has an important practical bearing, as perforation may take place as long as the serous surfaces are simply held together by adhesions, while such an occurrence is beyond the reach of all possibilities after the approximated surfaces have become united by living organized tissue. Adhesions between serous surfaces take place by the exudation of plastic lymph, which acts the part of a cement material; while on the other hand, the process of definitive healing is initiated by cell-proliferation from the pre-existing endothelial and connective tissue cells, and the formation of a network of new blood-vessels springing from each of the coaptated granulating surfaces. The processes are the same as we observe within blood-vessels during cicatrization after ligature. In suturing an intestinal wound, or in making a circular enterorrhaphy, it has always heretofore been deemed necessary not to injure the peritoneum unnecessarily, for fear that such injuries would result deleteriously by interfering with the prompt union between the sutured surfaces.

It is a well known fact in surgery that approximation of intact serous surfaces does not result in the formation of adhesions. When the surgeon desires to secure union between serous surfaces he resorts to mechanical irritation for the purpose of inducing a circumscribed plastic peritonitis, which invariably results in adhesions and the obliteration of the serous space. Reasoning from this analogy, I was induced to study the effects of traumatic and chemical irritation in hastening adhesions and cicatrization between apposed serous surfaces. In most of these experiments the serous surfaces in the different operations were held in contact by perforated approximation plates, and in case artificial means were employed to expedite the healing process, the fact is mentioned, and the result of such modification noted. The animals operated on were all dogs.

1. Traumatic Irritation of Serous Surfaces.

Time, Six Hours.

Experiment 93. The ileum was divided near the middle, and both ends closed by invagination and the continued suture. Ileo-ileostomy was made at two points, making two openings of communication. No suturing. Parts kept in apposition by perforated decalcified bone plates. To compare the effect of traumatic. irritation of the peritoneum in the reparative process

with the intact serous surface, the peritoneal surfaces at one point of operation designated as the upper, were scarified with the point of a needle over an area corresponding to the size of the bone discs, the scratches being made sufficiently deep to penetrate the entire thickness of the peritoneum. The scarifications were made in a longitudinal and transverse direction, mapping out the serous surfaces into small squares. Only slight oozing followed this procedure. The serous surfaces between the plates at No. 1, where no scarification was made, was found slightly adherent by a scanty deposit of plastic lymph. At No. 2, where scarifications had been done, the amount of plastic lymph was greater and stained by blood, and the adhesions much firmer.

TIME, TWELVE HOURS.

Experiment 94. In this experiment the bowel was not interrupted by division, but two adjacent coils of the ileum were united by making an ileo-ileostomy by perforated decalcified bone plates, the plates holding the parts perfectly in apposition; a slight tumefaction of the intestinal walls made the coaptation more secure. Coaptated serous surfaces very vascular, covered with a thin layer of plastic lymph which had agglutinated the folds of the intestine brought in contact.

Experiment 95. Bowel not divided, but two adjoining loops of the ileum united by making a double ileo-ileostomy by perforated approximation discs, the two communicating openings about six inches apart. At one point of operation, designated as No. 2, serous surfaces freely scarified. At both points the adhesions were perfect throughout, but where scarification was made they were notably firmer.

Experiment 96. In this experiment a gastro-enterostomy and an ileo-ileostomy were made at the same time and on the same animal. In both operations the parts were coaptated by perforated decalcified bone plates. Scarification of peritoneal surfaces at both places. The adhesions between the anterior surface of the stomach and upper portion of jejunum were uniform throughout, over the whole surface, kept in contact by the plates. There was no leakage on distending the stomach and intestine forcibly by water. The adhesions between the folds of the ileum at point of approximation were, if anything, firmer than between stomach and jejunum. The decalcified bone plate in the interior of the stomach was softened more than those in the intestine.

TIME, EIGHTEEN HOURS.

Experiment 97. Gastro-enterostomy by perforated decalcified bone plates; communication made between stomach and upper portion of jejunum; no scarification. Agglutination quite firm, so that forcible distention of stomach and bowel caused no leakage. New opening sufficiently large to admit middle finger, and apparently lined throughout by mucous membrane. Plate in stomach very much softened and on the verge of becoming detached. On forcibly separating the adhesions the serous surfaces were found to be cemented together by a thin layer of plastic lymph, and after scraping this away they appeared vascular and rough, as though completely deprived of the endothelial covering.

TIME, TWENTY-FOUR HOURS.

Experiment 98. Triple ileo-ileostomy without division of the bowel; the operations were numbered 1, 2, 3, respectively. Coaptation by approximation discs of decalcified bone. Communicating openings about six inches apart. In No. 1 no scarification. No. 2, scarification of one loop only. No. 3, scarification of both serous surfaces. After twenty-four hours the result was as follows:

No. 1. Lymph scanty; adhesions not very firm.

No. 2. Lymph more plentiful; adhesions firmer.

No. 3. Lymph more abundant than in No. 2, and mixed with a fine stratum of coagulated blood; adhesions also firmer. The adhesions increase in firmness in the order 1, 2, 3.

Experiment 99. Double gastro-enterostomy by perforated decalcified bone plates. The communicating openings, one near the pyloric, and the other near the cardiac extremity of the stomach, were made between the anterior surface of the stomach, and the upper portion of the jejunum. In operation No. 1, the intact serous surfaces near the pylorus were brought in contact, while in the second operation both the stomach and bowel were scarified. At the post-mortem, it was found that the adhesions at both places were of sufficient firmness to prevent leakage under pressure. In No. 2, adhesions firmer and the inflammatory infiltration more marked than in No. 1. Plates in stomach much softened, but remain *in situ.* Openings lined throughout by mucous membrane and sufficiently large to admit the index finger.

Experiment 100. Ileo-colostomy by lateral apposition and fixation by perforated approximation discs. Lower portion of ileum united with the ascending colon. No scarification; bowels lightly agglutinated throughout by a very thin layer of plastic lymph; adhesions, however, could be easily separated, and where this is done the peritoneal surface appeared denuded of endothelial cells, and very vascular with new vessels along the outer margin of the surface of approximation.

TIME, FORTY-EIGHT HOURS.

Experiment 101. Double gastro-enterostomy. The communicating openings were between the anterior surface of the stomach and the duodenum, and the posterior surface of the stomach and the upper portion of the jejunum. In the posterior operation the intact serous surfaces were brought in contact, while in the anterior, the peritoneal surfaces of the stomach and duodenum were scarified. In both operations perforated decalcified bone plates were used. Adhesions between posterior surface of stomach and bowel uniform throughout, but easily broken down; the peritoneal surfaces injected and apparently deprived of their endothelial covering. The anterior operation resulted in the formation of firm adhesions, the products of exudation and tissue proliferation being supplied with new vessels, the circumscribed plastic peritonitis being much more advanced than at the site of the posterior operation.

Experiment 102. Double ileo-colostomy by perforated approximation plates. The anastomosis between the lower portion of the ileum and the colon just above the cæcum was made without scarification, while in the second operation about six inches higher up in the colon and ileum, both serous surfaces were freely scarified. Omentum adherent at point of operation. Plates swollen, softened and pliable, but still efficient in maintaining coaptation and fixation. Adhesions at both places quite firm, but more so in the upper portion where scarification had been done.

Experiment 103. Ileo-colostomy by approximation discs. The ileum was divided a few inches above the ileo-cæcal region, and both ends closed by invagination and three stitches of the continued suture. An anastomosis was made between the proximal end and the ascending colon by lateral apposition. No scarification. Intestines agglutinated at point of operation, but the adhesions gave way when the bowel was forcibly distended under hydrant pressure.

2. Chemical Irritation of Serous Surfaces.

In these experiments it was aimed to study the effect of chemical irritation of the peritoneum in the reparative process after intestinal operations. Iodine has been used for a long time in producing plastic inflammation of serous surfaces for the purpose of obliterating serous cavities, consequently this substance was used in the first experiments. To study the effects of the diffuse application of tincture of iron to the intact peritoneal cavity, the following experiments were made:

Experiment 104. Medium-sized dog. The needle of a hypodermic syringe was thoroughly disinfected, and a drachm of the tincture of iodine injected into the peritoneal cavity. Immediately after the injection the animal evinced great pain, which, however, appeared to subside after a short time, and subsequently no unfavorable symptoms were observed. Three days after the injection the urine was examined and showed the presence of iodine. Dog killed nine days after the injection. Circumscribed plastic peritonitis over a space four inches square, corresponding to the point where the puncture was made. At this place the omentum was much thickened, very vascular and adherent to the parietal peritoneum and the adjoining folds of the intestines.

Experiment 105. Medium-sized dog. A fluid drachm of the tincture of muriate of iron was thrown into the peritoneal cavity by means of a well-disinfected hypodermic syringe. The pain immediately after the injection was intense, and the animal appeared to be very ill two days after the injection, and died with well-marked symptoms of peritonitis on the sixth day. Diffuse plastic peritonitis was found to be the cause of death. The omentum was adherent everywhere, and the intestines were matted together by numerous adhesions. The abdominal cavity contained a considerable quantity of serous fluid.

Remarks.—Both experiments prove that when tincture of iodine and tincture of iron are brought in contact with the peritoneum, a plastic inflammation ensues; and it was reasonable to expect that if either of these substances could be applied to the serous surfaces which it was intended to unite, the reparative process would be hastened.

Experiment 106. Triple ileo-ileostomy by perforated decalcified bone plates. Three internal fistulæ were made between the adjacent loops of the ileum, about six inches apart. In operation No. 1, approximation of intact serous surfaces; in operation No. 2, the serous surfaces were painted with tincture of iron over an area corresponding to the size of the plates; in operation No. 3, the serous surfaces over the same extent were brushed with pure tincture of iodine. The animal was killed forty-eight hours after operation, and the following conditions were noted: No general peritonitis. All the plates firmly in place coaptating the serous surfaces accurately, the swelling of the tunics of the bowel only serving to enhance their efficiency. At No. 1, adhesions quite firm, flexion of bowel and marked injection of serous surfaces. At No. 2, no adhesions between serous surfaces. The peritoneal surfaces to which the tincture of iron had been applied appeared stained, almost black, and at some points the serous coat was destroyed. At No. 3, peritoneal surfaces stained dark brown; adhesions firm, and an abundance of plastic lymph even beyond the margin of the plates.

Experiment 107. Double ileo-ileostomy by approximation plates and omental grafting. Operation No. 1, approximation of ileum to ileum by perforated decalcified bone plates; serous surfaces intact. Operation No. 2, similar operation six inches higher up uniting the same loops, but painting the serous surfaces with pure tincture of iodine. Operation 3, cutting off a piece of omentum two inches wide and sufficiently long to encircle the entire bowel. After scarifying the bowel and the omental graft on one side, the scarified surfaces were brought in contact, and the graft fixed in its place by two fine catgut sutures passed through the mesentery and both ends of the graft. Animal killed forty-eight hours after operation. All plates firmly in place. At No. 1, adhesions firm. At No. 2, dark-brown discoloration of surface to which the iodine had been applied; agglutination over the whole surface. Under hydrostatic pressure the adhesions first gave way between the two plates where the iodine had been applied; showing conclusively that chemical irritation of serous surfaces does not hasten the adhesive process, while it may, and probably does, expedite the definitive healing. At No. 3, omental graft firmly adherent to the entire circumference of the bowel, and beginning vascularization of the graft around its margins.

Remarks.—In all of these experiments the post-mortem examinations showed no evidences of diffuse peritonitis. In most of the cases the inflammatory process was limited to the portion of the bowel interposed between the plates. Without exception the

adhesions formed were firmest and the definitive healing was initiated first where scarification was performed; results which clearly demonstrate the fact that the reparative process between serous surfaces which it is intended to unite, is hastened by traumatic irritation. Traumatic irritation by scarification of the peritoneal surface with the point of an aseptic needle, is the most potent means to provoke a circumscribed plastic peritonitis, and is followed within a few hours by a copious exudation of plastic lymph, which, like a cement substance, mechanically agglutinates the coaptated serous surfaces. The same measure, by destroying the continuity of the non-vascular layer of the peritoneum, brings at once in contact the vascular network of both sides of the bowel, and opens up a direct route for the new vessels, an important element in the rapid healing of the visceral wounds. Chemical irritants by destroying the endothelial layer of the peritoneum rather retard, than favor, early adhesion and union between the coaptated bowels, and should therefore not be resorted to in intestinal surgery, to hasten the reparative process.

3. Omental Grafting.

Under the head of circular enterorrhaphy, mention is made of transplantation of omental flaps after uniting the two ends of the bowel by suturing or invagination, with a view of securing an additional safeguard against perforation during the process of repair. A number of experiments are described where the procedure was practiced with satisfactory results. After a few days the omental flaps were found firmly adherent and vascular around the whole circumference of the bowel, constituting a ring of living tissue outside the line of suturing. In all these cases the proximal end of the flap remained in connection with the omentum, and care was taken to cut the flap in such a manner that some vessel of considerable size should furnish the necessary vascular supply. I was well aware that plausible objections could be entered against this method, in that the connecting bridge between the bowel and the omentum might become subsequently a cause of intestinal obstruction by making traction upon the bowel, thus causing a flexion, or, by becoming a band of constriction for some loop of intestine.

For the purpose of obviating such remote consequences I resorted to another procedure which I have designated as omental grafting. I was familiar with the fact that implantations of aseptic

substances into the peritoneal cavity had frequently been done without any immediate or remote ill-effects, and I had every reason to expect that a large, completely detached, aseptic, omental graft, in an aseptic abdominal cavity, would be well tolerated, and would soon become adherent to the subjacent peritoneal surface, and thus afford an additional safeguard against perforation and the disastrous consecutive result, namely: perforative peritonitis during the time required for the healing of the intestinal wound. In the following experiments the grafts used were from one and a half to two inches in width, and of sufficient length to completely encircle the bowel. The free ends were made to project a few lines beyond the mesenteric attachment, and were fixed by two fine catgut sutures, each of which embraced the corresponding angles of the graft and the mesentery. The stitches were made in the direction of the mesenteric vessels, so that in tying, no vessels should be included in the suture. In these experiments dogs were used exclusively.

Experiment 108. Three pieces of omentum, two inches wide and sufficiently long to encircle the bowel, were completely detached and grafted as follows:

1. Graft simply laid over the bowel corresponding to the lower portion of the ileum, and fastened in its place on mesenteric side by two fine catgut sutures.

2. Serous surface of bowel about six inches higher up scarified, and graft applied to this surface and fixed in the same manner.

3. Bowel treated in the same way about six inches still higher up, and one of the serous surfaces of the graft also freely scarified.

The graft was scarified on the side which was to be brought in contact with the bowel. Fixation of graft by two catgut sutures on mesenteric side. Animal killed thirty-six hours after operation. All the grafts adherent, slightly contracting the bowel at the three different places. On separating the adhesions the subjacent serous surface very vascular and denuded of its endothelial layer. Firmness of adhesions increased in proportion to the extent of scarification done, being least firm at No. 1, firmer at No. 2, and firmest at No. 3, where both coaptated serous surfaces had been scarified. At Nos. 2 and 3, the plastic lymph was freely supplied with new blood-vessels. The vascularization was most conspicuous on the mesenteric side.

Experiment 109. Two omental grafts planted around the ileum in the same manner as described above. At No. 1, both the bowel and the inner side of the graft were scarified; at No. 2, only the serous surface of the bowel. Animal killed forty-three hours after operation. Stump of omentum adherent to abdominal wound and intestines. No peritonitis. At No. 1, graft firmly adherent over the entire extent. A slight extravasation of blood between the graft and the bowel. Beginning vascularization of interposed plastic lymph.

At No. 2, also firm adhesions and beginning vascularization of the plastic exudation. Both of the grafts appear to be stained with the coloring material of the blood.

Experiment 110. Planting of two omental grafts around the ileum about eight inches apart. At No. 1, both the bowel and one side of the omental graft were scarified. At No. 2, only the serous surface of the bowel was treated in this manner. Animal killed six days after the operation. Both grafts firmly adherent throughout and freely supplied with blood-vessels, the largest of the new vessels being on the mesenteric side. The omental stump adherent to the portion of bowel between the grafts where a flexion had been made from this cause.

Experiment 111. In this experiment omental grafting was done at two points around the lower portion of the ileum. At one point the serous surfaces were left intact, at the other, both the peritoneal surface of the bowel and the omental graft were freely scarified. Animal remained perfectly well and was killed eight days after operation. No signs of peritonitis. Both grafts formed a thin vascular layer around the entire circumference of the bowel, and firmly and evenly united throughout. Vascularization was more marked where scarification had been done. On attempting to separate the grafts it was difficult to find and define the line of union between the omentum and the underlying bowel, as the union was very intimate and firm.

Remarks.—In all of these experiments the grafts retained their vitality, and in a few hours became firmly adherent to the intestinal surface with which they had been brought in contact. Scarification of the serous surface has also been found in these experiments, an exceedingly valuable measure in hastening the processes of adhesion, granulation and vascularization. By planting grafts side by side, with and without scarification, I was enabled to determine with accuracy the beneficial influence exerted by this procedure in favoring the reparative process, and without a single exception, observed that where scarification was done the adhesions were firmer and vascularization more advanced. The post-mortem examinations appeared to demonstrate that the firmness of the adhesions and the degree of vascularization were in direct proportion to the extent of traumatic irritation of the peritoneum, being always most marked in cases where both the bowel and the under surface of the graft were scarified, and least where intact peritoneal surfaces were brought into apposition.

As soon as the omental grafts were cut off from the omentum they were placed in a 1-2000 solution of corrosive sublimate, kept at the temperature of the body, in order to secure for the graft a perfectly aseptic condition until everything was in readiness for

the transfer of the graft to its new location. Before planting the graft it was carefully dried by pressing it between gauze or sponges wrung out of the same solution. The scarifications of the serous surfaces should only be made sufficiently deep to give rise to a very slight oozing, as when hæmorrhage is more profuse, there is danger of the formation of a clot between the graft and the bowel, which, if it does not ultimately prevent union between the coaptated surfaces, must necessarily interfere with the formation of early and firm adhesions.

Omental grafting cannot fail to become an established procedure in many abdominal operations. After suturing a large wound of the stomach or intestines, a strip of omentum should be laid over the wound and fastened in its place by a few catgut sutures. After circular enterorrhaphy, the operation should be finished by covering the circular wound by an omental graft about two inches wide, which should be fixed in its place by two catgut sutures passed through both ends of the graft and the mesentery. Omental grafting should also be resorted to in repairing peritoneal defects in visceral injuries of the abdominal organs, and in covering large stumps after ovariotomy or hysterectomy, where the pedicle is treated by the intra-abdominal method.

VI. Conclusions.

In conclusion I beg leave to submit the following propositions for further discussion :

1. Traumatic stenosis from partial enterectomy and longitudinal suturing of the wound becomes a source of danger from obstruction or perforation, in all cases where the lumen of the bowel is reduced more than one-half in size.

2. Longitudinal suturing of wounds on the mesenteric side of the intestine should never be practiced, as such a procedure is invariably followed by gangrene and perforation by intercepting the vascular supply to the portion of bowel which corresponds to the mesenteric defect.

3. The immediate cause of gangrene in circular constriction of a loop of intestine is due to obstruction of the venous circulation. and takes place first in the majority of cases at a point most remote from the cause of the obstruction.

4. On the convex surface of the bowel a defect an inch in width, from injury or operation, can be closed by transverse suturing without causing obstruction by flexion. In such cases the stenosis is subsequently corrected by a compensating bulging or dilatation of the mesenteric side of the bowel.

5. Closing a wound of such dimensions on the mesenteric side of the bowel by transverse suturing may give rise to intestinal obstruction by flexion, and to gangrene and perforation by seriously impairing the arterial supply to, and venous return from, the portion of bowel corresponding with the mesenteric defect.

6. Flexion caused by inflammatory and other extrinsic causes gives rise to intestinal obstruction only in case the functional capacity of the flexed portion of the bowel has been impaired or suspended by the causes which have produced the flexion, or by subsequent pathological conditions which have occurred independently of the flexion.

7. As in flexion, a volvulus gives rise to symptoms of obstruction, when the causes which have given rise to a rotation upon its axis of a loop of bowel have at the same time produced an impairment or suspension of peristalsis in the portion of bowel which constitutes the volvulus; or when a diminution or suspension of peristalsis follows in consequence of the degree or extent of the rotation.

8. Accumulation of intestinal contents above the seat of invagination is one of the most important factors which prevents spontaneous reduction, and which determines gangrene of the intussusceptum and perforation of the bowel.

9. Spontaneous disinvagination is not more frequent in ascending than descending invagination.

10. The immediate or direct cause of gangrene of the intussusceptum is obstruction to the return of venous blood by constriction at the neck of the intussuscipiens.

11. Ileo-cæcal invagination, when recent, can frequently be reduced by distention of the colon and rectum with water; but this method of reduction must be practiced with the greatest caution and gentleness, as over-distention of the colon and rectum is productive of multiple longitudinal lacerations of the peritoneal coat, an accident which is followed by the gravest consequences.

12. The competency of the ileo-cæcal valve can only be overcome by over-distention of the cæcum, and is effected by a mechanical separation of the margins of the valve; consequently it is imprudent to attempt the treatment of intestinal obstruction beyond the ileo-cæcal region by injections per rectum.

13. Resection of more than six feet of the small intestine in dogs is uniformly fatal; the cause of death in such cases is always attributable to the immediate effects of the trauma.

14. Resection of more than four feet of the small intestine in dogs is incompatible with normal digestion, absorption and nutrition, and often results in death from marasmus.

15. In cases of extensive intestinal resection, the remaining portion of the intestinal tract undergoes compensatory hypertrophy, which microscopically is apparent by thickening of the intestinal coats and increased vascularization.

16. Physiological exclusion of an extensive portion of the intestinal tract does not impair digestion, absorption and nutrition as seriously as the removal of a similar portion by resection.

17. Fæcal accumulation does not take place in the excluded portion of the intestinal canal.

18. The excluded portion of the bowel undergoes progressive atrophy.

19. A modification of Jobert's invagination suture by lining the intussusceptum with a thin flexible rubber ring, and the substitution of catgut for silk sutures is preferable to circular enterorrhaphy by the Czerny-Lembert suture.

20. The line of suturing, or neck of intussuscipiens, should be covered by a flap or graft of omentum in all cases of circular resection, as this procedure furnishes an additional protection against perforation.

21. In circular enterorrhaphy, the continuity of the peritoneal surface of the ends of the bowel to be united should be procured where the mesentery is detached, by uniting the peritoneum with a fine catgut suture before the bowel is sutured, as this modification of the ordinary method furnishes a better security against perforation on the mesenteric side.

22. In cases of complete division of an intestine, if it is deemed advisable not to resort to circular enterorrhaphy, one or both

ends of the bowel should be closed by invagination to the depth of an inch, and three stitches of the continued suture embracing only the peritoneal and muscular coats.

23. The formation of a fistulous communication between the bowel above and below the seat of the obstruction should take the place of resection and circular enterorrhaphy in all cases where it is impossible or impracticable to remove the cause of obstruction, or where after excision it would be impossible to restore the continuity of the intestinal canal by suturing, or where the pathological conditions which gave rise to the obstruction do not constitute an intrinsic source of danger.

24. The formation of an artificial anus in the treatment of intestinal obstructions should be practiced only in cases where continuity of the intestinal canal cannot be restored by making an intestinal anastomosis.

25. Gastro-enterostomy, jejuno-ileostomy and ileo-ileostomy should always be made by lateral apposition with partially or completely decalcified perforated bone plates.

26. In making an intestinal anastomosis for obstruction in the cæcum, or colon, the communication above and below the seat of obstruction can be established by lateral apposition with perforated approximation plates, or by lateral implantation of the ileum into the colon or rectum.

27. An ileo-colostomy, or ileo-rectostomy by approximation with decalcified perforated bone plates, or by lateral implantation, should be done in all cases of irreducible ileo-cæcal invagination, where the local signs do not indicate the existence of gangrene or impending perforation.

28. In all cases of impending gangrene or perforation, the invaginated portion should be excised, both ends of the bowel permanently closed, and the continuity of the intestinal canal restored by making an ileo-colostomy or ileo-rectostomy.

29. The restoration of the continuity of the intestinal canal by perforated approximation plates, or by lateral implantation, should be resorted to in all cases where circular enterorrhaphy is impossible on account of the difference in size of the lumina of the two ends of the bowel.

30. In cases of multiple gunshot wounds of the intestines involving the lateral or convex side of the bowel, the formation of intestinal anastomosis by perforated decalcified bone plates should be preferred to suturing, as this procedure is equally, if not more safe, and requires less time.

31. Definitive healing of the intestinal wound is only initiated after the formation of a network of new vessels in the product of tissue proliferation from the approximated serous surfaces.

32. Under favorable circumstances quite firm adhesions are found within the peritoneal surfaces in six to twelve hours, which effectually resist the pressure from within outward.

33. Scarification of the peritoneum at the seat of coaptation hastens the formation of adhesions and the definitive healing of the intestinal wound.

34. Omental grafts, from one to two inches in width, and sufficiently long to completely encircle the bowel, retain their vitality, become firmly adherent in from twelve to eighteen hours, and are freely supplied with blood-vessels in from eighteen to forty-eight hours.

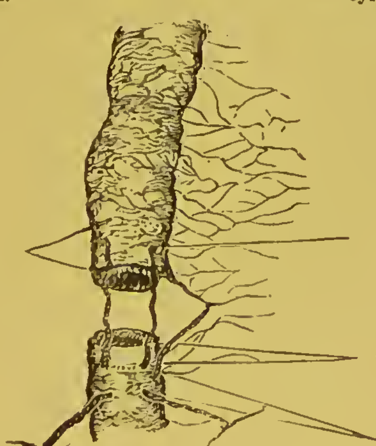
35. Omental transplantation, or omental grafting, should be done in every circular resection or suturing of large wounds of the stomach or intestines, as this procedure favors healing of the visceral wound, and affords an additional protection against perforation.

Methods of Intestinal Anastomosis.

Intestinal Anastomosis by Perforated Decalcified Bone-Plates.

Plate within colon below seat of obstruction.

Approximation of intestine by tying of sutures.



Author's Modification of Jobert's Suture.

RECTAL INSUFFLATION OF HYDROGEN GAS AN INFALLIBLE TEST IN THE DIAGNOSIS OF VISCERAL INJURY OF THE GASTRO-INTESTINAL CANAL IN PENETRATING WOUNDS OF THE ABDOMEN.

The operative treatment of penetrating wounds of the abdomen complicated by visceral injury of the gastro-intestinal canal is now sanctioned by the best surgical authorities, and may be considered as a well-established procedure, based as it is upon the results of experimentation and clinical experience. A visceral wound of the stomach or any portion of the intestinal canal sufficient in size to give rise to extravasation into the peritoneal cavity, must be looked upon as a mortal injury unless promptly treated by abdominal section. A number of well authenticated cases are on record where a wound in the stomach or the large intestine healed, and the patients recovered without the intervention of surgery, but these instances are so few that, practically, the force of the preceding statement remains unimpaired. After a careful study of an immense amount of clinical material Otis came to the important conclusion that gunshot injuries of the small intestines under the old expectant treatment, without exception resulted in death; and that is a sufficiently cogent argument in favor of their treatment by laparotomy as affording the only chance of recovery.

The great difficulty that presents itself to the surgeon in the absence of positive symptoms, is the differential diagnosis between a simple penetrating wound and a penetrating wound complicated by injury of the gastro-intestinal canal. While the existence of serious intra-abdominal hæmorrhage can usually be readily recognized by well marked physical signs and a complexus of symptoms which points to sudden diminution of intra-arterial pressure, and thus furnishes one of the positive indications for treatment by laparotomy,

the well-known fact remains that a visceral injury of the stomach or intestines seldom gives rise to symptoms upon which the surgeon could rely in making a positive diagnosis.

In the treatment of penetrating wounds of the abdomen laparotomy is resorted to either (1) for the purpose of arresting dangerous hæmorrhage, or (2) for the detection and treatment of a wound or wounds of its hollow viscera. The first indication is readily recognized, and the diagnosis not only justifies the operation, but imposes it as a stern duty upon the surgeon, from which he should never shrink. The recognition of the second indication offers greater difficulties, and the uncertainty of diagnosis which surrounds such cases is used as a sufficient argument by many in opposing the adoption of timely and efficient surgical treatment, and is responsible for the loss of many lives which otherwise might have been saved. The uncertainty of diagnosis must remain in the way of a more general adoption of laparotomy in the treatment of penetrating wounds of the abdomen, in the case of timid surgeons, and the same cause may lead to most unpleasant medico-legal complications in the practice of bolder and more aggressive operators.

Clinical experience and statistics have demonstrated the importance of making a distinction between punctured and gunshot wounds in the abdomen, both in reference to diagnosis and treatment. It is well known that penetrating stab-wounds are less likely to be complicated by visceral injury than bullet wounds, consequently this class of injuries offers a more favorable prognosis and does not call so uniformly for treatment by abdominal section. That penetrating gunshot wounds of the abdomen do not always implicate the gastro-intestinal canal has been well demonstrated by experiment and clinical observation. During the last two years three cases of bullet wounds of the abdomen came under my observation where no doubt could be entertained that penetration had taken place, and yet all the patients recovered without operation. In all three cases the bullet had taken an antero-posterior direction. As in private practice the treatment of penetrating wounds of the abdomen usually involves great medico-legal responsibilities, it becomes of the greatest importance to arrive at positive conclusions in reference to the character of the injury, before the patient is subjected to the additional risks to life incident to an abdominal section.

We will suppose a case. In a quarrel a man is shot in the abdomen. The assailant is placed under arrest. The surgeon who is called establishes the fact that the bullet has entered the abdominal cavity, and from the point of entrance and its probable direction, he has reason to believe that it has wounded some part of the gastro-intestinal canal, and he concludes to verify his diagnosis by an exploratory laparotomy; the operation is performed, and the most careful examination made, but no visceral wound is found. The wound is closed and the patient dies on the third or fourth day of septic peritonitis. The attorney for the state charges the defendant with murder.

The defense will very naturally raise the questions: "Did the man die of the injury, or the operation?" "Shall the defendant be tried for assault and battery, or for murder?" During the trial the attending surgeon is made the target for a volley of a medley of scientific and unscientific questions by the cunning attorney for the defense in his attempt to save his client from the gallows or state prison for life, at the expense of the reputation of the surgeon and the respect and good name of the art and science of surgery. This picture is not overdrawn. Such cases have happened and will happen again. It is apparent that if some infallible diagnostic test could be applied in cases of penetrating wounds of the abdomen which would indicate to the surgeon the presence or absence of visceral lesions of the gastro-intestinal canal, the indication for aggressive treatment would become clear and the medico-legal responsibility of the operator would be reduced to a minimum.

As we can never expect by a study of symptoms or by the ordinary physical examination to fill this gap, I was induced to search for some reliable test which in such cases should prove that the penetrating bullet or instrument had injured the gastro-intestinal canal. It occurred to me that a wound in the stomach or intestine should be sought for in some such way as the plumber locates a leak in a gas-pipe. The first object to be accomplished was to prove the permeability of the entire gastro-intestinal canal to inflation of air, and the next step was to find some innocuous gas which, when inflated, would escape from the intestinal wound into the peritoneal cavity, and from there through the external wound, where its presence could be proved by some infallible test.

I. Permeability of the Ileo-Cæcal Valve to Rectal Insufflation of Air or Gas.

A great deal has been said and written in reference to the permeability of the ileo-cæcal valve to injections of fluids into the rectum, or to the insufflation of air or gases. The majority of those who have studied this subject clinically or by experiment make the positive assertion that the ileo-cæcal valve is perfectly competent, and effectually guards the ileum against the entrance of both fluids and gases forced into the rectum, while others insist that it is permeable only in exceptional cases, and only a few claim that its resistance can be overcome by a moderate degree of pressure. Heschl[1] made a number of experiments and satisfied himself that the ileo-cæcal valve serves as a safe and perfect barrier against the entrance of fluids from below. In testing the resisting power of the coats of the intestine he found that the serous coat of the colon gave way first to overdistention, while the remaining tunics yielded subsequently to a somewhat slighter pressure. The small intestine of a child on being subjected to overdistention ruptured first on the mesenteric side, the place where acquired diverticula are found.

Bull[2] has found that in the adult one litre of water injected by the rectum will reach the cæcum, but that the entire capacity of the large intestine is from four to five litres. He is of the opinion that in the living body, fluid cannot be forced beyond the ileo-cæcal valve, although ancient and modern experimenters claim to have succeeded in the cadaver. He affirms that when the rectum is distended by air, the ileo-cæcal valve is rendered incompetent and the air passes into the small intestines.

Cantani[3] is a firm believer in the permeability of the ileo-cæcal valve to fluid rectal injections. In one instance he treated a case of coprostasis by an injection of a litre and a half of oil per rectum, and an hour later a part of the oil was ejected by vomiting. He advises that the intestinal tract above the ileo-cæcal valve should be utilized as an absorbing surface in cases requiring rectal alimenta-

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[1] Zur Mechanik diastaltischen Darmperforationen. Wiener Med. Wochenschrift, No. 1, 1881.

[2] Virchow's Jahresbericht, B. 11, 1878, S. 205.

[3] Virchow's Jahresbericht, B. 11, 1879, S. 180.

tion, and that when in a diseased condition it should be treated by topical applications.

Behrens[1] concluded from his experiments that it required the insufflation per rectum of one and one-eighth litres of air to reach the ileum through the ileo-cæcal valve. In his experiments he had no difficulty in overcoming the competency of the ileo cæcal valve by rectal insufflation of air.

Debierre[2] made numerous experiments on the cadaver to test the permeability of the ileo-cæcal valve to rectal injections of fluids or inflation of air. The results which he obtained were not constant. In some subjects the valve proved only permeable to air, in others, to both air and water, while in some no air or fluids could be forced into the ileum by any degree of force. When the intestine was left *in situ* the valve was found less permeable than when the intestine had been removed from the body. He attributed the different degrees of competency of the valve to variations in the anatomical construction of the valve. If both lips of the valve were equal in length, or if the lower lip was longer the valve was found impermeable. It proved permeable in cases where the lower lip was shorter, contracted, and smaller than the upper. In the last instance, the advancing volume of fluid or air lifted the upper valve, while in the former structure of the valve, the margins of the lips of the valve were pressed against each other, perfectly shutting off all communication between the colon and the ileum.

Mr. Lucas[3] enumerates the following objections against forcible rectal injections of water as a means of reducing invagination:

1. Owing to its weight it exerts much too strong lateral pressure for the intestine safely to bear, and he has found it easy to rupture the bowel after death by forcing in water.

2. Should reduction have been accomplished, the contact of a large quantity of water with the large bowel is apt to increase the tendency to diarrhœa. He claims very properly, that air, on the other hand, is a natural occupant of the intestinal canal, and whilst

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[1] Ueber den Werth der Künstlichen Auftreibung des Dickdarmes mit Gasen u. Flüssigkeiten. Göttingen. Dissertation. 1886.

[2] La valvule de Bauhin considérée comme barrière des apothicaires. Lyon Médicale, No. 45, 1885.

[3] On Inversion with Inflation in the Cure of Intussusception. The Lancet, January 16, 1886.

its pressure is of the gentlest its presence excites no unnatural peristaltic action. He administers an anæsthetic to the point of relaxation before the inflation is attempted.

Dawson[1] made a number of experiments on the cadaver and came to the conclusion that when the ileo-cæcal valve is in a normal condition it effectually guards the small intestine against the ingress of fluids from below. Illoway[2] has devised a force-pump which he strongly recommends for the purpose of forcing water beyond the ileo-cæcal valve, in case the seat of an intestinal obstruction is located above that point. He reports four cases of intestinal obstruction treated by this method, three of which recovered. Battey[3] asserts the permeability of the entire alimentary canal by enema, and verifies his statement by the recital of his own clinical experience and experiments upon the cadaver.

Ziemssen recommends inflation of the rectum for diagnostic and therapeutic purposes and proceeds as follows: A rectal tube about six inches long is carried into the anus and fixed by pressing together the nates, the patient lying on the back. A funnel is then connected with the rectal tube by means of rubber tubing. For complete inflation of the large intestine three drams of bicarbonate of soda and four and a half drams of tartaric acid are separately dissolved in water and portions of either solution alternately added. To prevent sudden overdistention of the bowel it is advised to add the solutions at intervals of several minutes. A very important use of this method is to diagnosticate the position of contractions, strictures, or occlusion of the intestine in cases in which it is desirable to operate, and also to show the position of peritoneal adhesions. The result of his observations has led him to believe that, as a rule, the small intestine is completely closed to the entrance of substances from the colon, by the ileo-cæcal valve. Under the influence of deep chloroform narcosis, however, this resistance is lessened, and fluids can be thrown into the small intestine.

Since this work has gone to press my attention has been called by Dr. Eastman, of Indianapolis, to a paper on "Fifty Laparotomies," etc., which he published in Progress, for January, 1888, in which

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[1] Lancet and Clinic, Feb. 21, 1885.

[2] American Journal Medical Sciences, Vol. 41, p. 168.

[3] Transactions of the American Medical Association, 1878.

he describes a case of pelvic abscess where he resorted to Bergeon's method of rectal insufflation of sulphuretted hydrogen gas after the abscess was opened, to determine whether it communicated with the large intestine. In the same paper appears a case of resection of the colon where the same test was used after suturing, to prove the efficiency of the sutures.

In my paper read at the last International Medical Congress[1] the following experiments appear, which illustrate the difficulty in overcoming the resistance of the ileo-cæcal valve by rectal injections of water:

Experiment 23. While completely under the influence of ether, an incision was made through the linea alba of a cat, sufficiently long to render the ileo-cæcal region readily accessible to light. An incision was made into the ileum just above the valve and by gently retracting the margins of the wound, the valve could be distinctly seen. Water was then injected into the rectum, and as the cæcum became well distended it could be readily seen that the valve became tense and appeared like a circular curtain, preventing effectually the escape even of a drop of fluid into the ileum. The competency of the valve was only overcome by overdistention of the cæcum, which mechanically separated its margins, allowing a fine stream of water to escape into the ileum. The insufficiency of the valve was clearly caused by great distention of the cæcum. That such a degree of distention is attended by no inconsiderable danger, was proved by this experiment, as the cat was immediately killed, and on examination of the colon and rectum, a number of longitudinal rents of the peritoneal coat was found.

Experiment 24. In this experiment a cat was fully narcotized with ether and while the body was inverted, water was injected per rectum in sufficient quantity and adequate force, by means of an elastic syringe, to ascertain the force required to overcome the resistance offered by the ileo-cæcal valve. Great distention of the cæcum could be clearly mapped out by percussion and palpation before any fluid passed into the ileum. As soon as the obstruction at the valve was overcome, the water rushed through the small intestines, and having traversed the entire alimentary canal, issued from the mouth. About a quart of water was forced through in this manner. The animal was killed and the gastro-intestinal canal carefully examined for injuries. Two longitudinal lacerations of the peritoneal surface of the rectum, over an inch in length, were found on opposite sides of the bowel.

Experiment 25. This experiment was conducted in the same manner as the foregoing, only that the cat was not etherized. More than a quart of water was forced through the entire alimentary canal from anus to mouth. The animal lived for eight days, but suffered during the whole time with

[1] An Experimental Contribution to Intestinal Surgery with Special Reference to the Treatment of Intestinal Obstruction.

symptoms of ileo-colitis. A post-mortem examination was not made, although the symptoms manifested during life leave no doubt that they resulted from injuries inflicted by the injection.

It will thus be seen that in the three cases where fluid was forced beyond the ileo-cæcal valve, in two of them the post-mortem revealed multiple lacerations of the peritoneal coat of the large intestines, while the third animal sickened immediately after the experiment was made, and died eight days later from the effects of the injuries inflicted. These experiments combined with clinical experience leave no further doubt that, practically, the ileo-cæcal valve is not permeable to fluids from below, and that for diagnostic and therapeutic uses it is unsafe and unjustifiable to attempt to force fluids beyond the ileo-cæcal valve. We should *a priori* expect that air and gases, on account of their less weight and greater elasticity than water, could be forced along the intestinal canal with less force, and for that reason alone, if for no other, should be preferred to water in cases where it appears desirable to distend the intestine above the ileo-cæcal valve. The results obtained by experimental research in the past speak in favor of rectal inflation by air or gas in all cases where for diagnostic or therapeutic purposes it becomes necessary to dilate the entire or a portion of the gastro-intestinal canal.

I. Rectal Insufflation of Air.

Experiment 1.[1] Dog, weight seventy-five pounds. The animal was profoundly anæsthetized, and by means of an ordinary elastic syringe, air was forced through the rectum until the whole abdomen became distended and tympanitic. The abdominal cavity was opened in the median line, and the whole intestinal canal was found distended. An incision about an inch in length was made about the middle of the small intestines, when air escaped. and about one foot of the intestine on either side of the wound collapsed. The remaining portion of the intestines remained unaffected by the incision. The animal was killed, and every part of the entire gastro-intestinal canal carefully examined for injuries. The ileo-cæcal valve remained intact, and no evidence of rupture of any of the coats of the intestines could be detected.

Experiment 2. Dog, weight twelve pounds. Under full anæsthesia the gastro-intestinal canal was inflated in the same manner as in the preceding experiment, and the inflation was carried to the same extent. On opening the

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[1] These experiments were made at the County Hospital, and my thanks are due to Dr. M. E. Connel, superintendent of the hospital, and his assistants, and Dr. Wm. Mackie of Milwaukee, for valuable assistance.

abdomen in the median line the distended loops of the intestines protruded from the wound, and partial exventration was allowed to take place for the purpose of examining the intestine for injuries. The closest inspection failed to detect evidences of partial or complete rupture of any of the tunics. One of the distended coils of intestine was incised at opposite points on the lateral aspect, the incisions being an inch in length. Only a limited segment of the bowel on each side of the wounds collapsed, and although the peristalsis was active, more remote portions were emptied very slowly. The wounds were united transversely for the purpose of making an artificial diverticulum. The animal recovered without any untoward symptoms.

Experiment 3. Dog, weight thirteen pounds. Animal profoundly etherized, and air inflated as in former experiments. The distended colon could be clearly mapped out by percussion before a gurgling sound in the region of the ileo-cæcal valve indicated that the air had entered the ileum. After this had occurred the middle of the abdomen became prominent and tympanitic. As soon as the resistance offered by the ileo-cæcal valve had been overcome, it required less force to distend the remaining portion of the gastro-intestinal canal. The inflation was carried to the extent of distending the stomach, an event which was easily recognized by a considerable prominence in the epigastric region which was tympanitic on percussion. At this time an elastic tube was inserted into the stomach, and its free end immersed under water. Bubbles of air escaped freely, and the abdominal distention was materially diminished. As the inflation was continued the air would escape through the stomach-tube, showing that a moving current of air existed between the rectal tube and the stomach tube. The abdominal distention which remained after the experiment had completely disappeared after eighteen hours, and the animal never manifested pain or any other symptoms of disease.

Experiment 4. Dog, weight fifteen pounds. In this experiment inflation was practiced without anæsthesia. The rigidity of the abdominal muscles greatly interfered with the distention of the colon to a requisite degree to overcome the competency of the ileo-cæcal valve. The passage of air from the cæcum into the ileum through the ileo-cæcal valve was announced by an audible gurgling-sound which was repeated at intervals, as the cæcum, after partial collapse, was again distended by renewing the inflation. The insufflation was continued until the stomach became distended by air, which caused vomiting and copious eructations of air. The dog remained in perfect health after the inflation.

These experiments prove the feasibility of forcing air through the entire alimentary canal from below upwards. In not a single experiment could any structural changes be found in the walls of the intestine, and all animals not killed immediately after the experiment recovered. The results of these experiments contrast strongly with those by rectal injections with water where the same objects were in

view. In the latter experiments the force requisite to overcome the ileo-cæcal valve invariably produced lacerations of the peritoneal coat of the bowel, which in themselves would constitute a grave source of danger.

It now became necessary for me to prove that the ileo-cæcal region in man in so far resembled that of the dog, that the ileo-cæcal valve could be rendered more readily incompetent by inflation of air than by injections of fluids. The following two experiments were made for this purpose:

Experiment 5. A young man, twenty-five years of age, a patient in the Milwaukee Hospital, under treatment for a tumor in the epigastric region, was subjected to the experiment. He was placed flat on the back. On percussion the whole umbilical region was found flat and the abdominal wall retracted. No anæsthesia. With an ordinary elastic syringe air was injected slowly into the rectum. As inflation progressed the outlines of the entire colon could be clearly seen and accurately mapped out by percussion. The cæcal region especially became very prominent. The inflation was continued very slowly, and as soon as the air passed through the ileo-cæcal valve, the hypogastric and umbilical regions began to rise and resonance replaced the former dullness on percussion. The arrival of air in the stomach was indicated by distention of the epigastric region, disappearance of the contour of the tumor and resonance on percussion. During the whole process of inflation the patient only complained of a slight pain in the splenic flexure of the colon, and a sensation of fullness in the abdomen. As soon as it became apparent that the stomach was distended by air, a stomach-tube was introduced and its free end placed under water. As the inflation was continued, bubbles of air continued to escape. On assuming the erect position the patient complained of colicky pains in the umbilical region, which were undoubtedly caused by an exaggerated peristalsis. The pain, however, soon disappeared, and on the following day he was as well as usual.

Experiment 6. Adult male, suffering from neurasthenia. Experiment and result the same as in No. 5, only that in this case the pain due to distention of the colon was referred to the ileo-cæcal region, and the colicky pain in the umbilical region persisted for a longer time. The air was again forced from anus to mouth without causing any injury whatever and only moderate degree of pain for a short time.

The foregoing experiments demonstrate conclusively that in the human subject by a moderate degree of force, short of producing any injury of the tunics of the intestines, air can be forced along the entire alimentary tract, and that this procedure can be resorted to with perfect safety for diagnostic and therapeutic purposes in all cases where the tissues of the intestinal wall have not suffered too much loss of resistance from antecedent pathological changes.

2. Inflation of Alimentary Canal through Stomach Tube.

We should naturally expect that the alimentary canal could be inflated with more ease and with a less degree of force by following the normal peristaltic wave. That this is not the case will be seen from the following experiments:

Experiment 7. Dog, weight forty pounds (18 kilograms). After complete anæsthesia was effected a flexible rubber tube was introduced into the stomach, and the free end of the tube connected with a four-gallon rubber balloon containing hydrogen gas, by means of a rubber tube. Between the gas reservoir and the stomach-tube a manometer was interposed, registering accurately the force used in making the inflation. The inflation was made by compressing the rubber bag. A tube was introduced into the rectum to facilitate the escape of gas that might reach this portion of the intestinal tract. Under a pressure of one pound and a half the stomach dilated rapidly, and later the entire abdomen became distended and resonant on percussion, but no gas escaped per rectum. When the pressure was increased to two pounds (.9 kilogram), no further distention of the abdomen took place, as the gas escaped along the side of the stomach tube. At this time respiration became greatly embarrassed, but was relieved on allowing gas to escape through the stomach-tube. On compressing the abdomen firmly the distention disappeared almost completely; at the same time a large quantity of gas continued to escape through the stomach-tube. Inflation was renewed, and under a pressure of one pound and a half, the abdomen again became uniformly distended. When the pressure was increased to two pounds (.9 kilogram) the dog suddenly died, and all efforts at resuscitation failed. On opening the abdomen the stomach was found enormously distended, reaching three inches below the umbilicus, occupying almost the entire abdominal cavity. The upper half of the small intestines was distended; numerous points of sharp flexions were found among the different distended coils. The distended stomach had evidently encroached so much upon the abdominal space as to render the greater part of the intestinal canal impermeable by pressure.

Experiment 8. Dog, weight fifteen pounds. After the animal was placed fully under the influence of ether, the abdomen was opened and the cæcum and lower portion of ileum drawn forward into the wound, and a large aspirator needle inserted into the ileum just above the ileo-cæcal valve. Through a rubber tube hydrogen gas was forced into the stomach. Under one pound (.45 kilogram) of pressure, the stomach and upper portion of the intestines dilated readily. When the force was increased, the gas returned through the œsophagus along the sides of the stomach-tube.

Experiment 9. Dog, medium size. This animal was killed to ascertain the results of an experiment made for another purpose. Rubber balloon containing hydrogen gas, and manometer were used for making the inflation. The tube through which the inflation was made was tied in the œsophagus. The abdomen was distended enormously, and on increasing the pressure to

three and three-fourths pounds (1.7 kilograms), still no gas escaped through the rectal tube. The abdomen was then opened, when the stomach was found so enormously distended that it filled almost the entire abdominal cavity. About one-fourth of the length of the small intestines was found distended, and among the distended loops numerous acute flexions could be seen. After the abdomen was opened, under long and continuous distention, the peritoneal covering of the stomach gave way, when the manometer registered only one pound and a half of pressure.

Experiment 10. Dog, weight eighteen pounds (8 kilograms). Immediately after death the œsophagus was isolated and the tube of the hydrogen gas inflator securely tied in, and a glass tube was inserted into the rectum. Under a pressure of two and three-fourths pounds (1.2 kilograms), registered by the manometer, the gas first dilated the stomach and then passed along the intestines until it escaped in a steady stream through the rectal tube, where it was ignited. On opening the abdomen the stomach was found greatly distended, while the distention of the intestines was a great deal less marked. None of the tunics of the stomach or intestines were injured.

Experiment 11. Dog, weight twenty pounds (9 kilograms). Animal etherized and a flexible tube connected with the gas inflator introduced into the stomach, and a glass tube into the rectum. On inflation the stomach became gradually distended, and when the pressure had reached one pound and a half (.7 kilogram), the dog vomited and a good deal of gas escaped at the same time. Inflation was again commenced and was followed by uniform distention and tympanites over the entire abdomen; when the pressure reached two pounds and a half (1.1 kilograms), the gas escaped from the rectum, and when ignited burned with a steady blue flame. The experiment was followed by no unfavorable symptoms.

Experiment 12. Dog, weight twelve pounds (5.4 kilograms). Under the influence of ether inflation with hydrogen gas in the same manner as in last experiment. As soon as the stomach became well distended, and the manometer registered one pound and a half of pressure, vomiting occurred, attended by a free escape of gas, which was followed by collapse of the distended epigastric region. When inflation was resumed, it was noted that any increase of pressure over one pound (.45 kilogram) was followed by regurgitation of gas, and on this account it was found impossible to inflate the lower portion of the intestinal tract. No unfavorable symptoms followed the experiment.

Experiment 13. Dog, weight twenty-eight pounds (12.7 kilograms). Under the influence of ether inflation of hydrogen gas through the stomach tube. As soon as the pressure was increased to more than one pound (.45 kilogram) the gas escaped along the sides of the tube through the œsophagus; consequently only the upper portion of the abdomen could be distended, and the inflation evidently did not extend much beyond the stomach. The experiment was repeated several times with the same result. The animal remained perfectly well after the experiment.

Experiment 14. Dog, weight twelve pounds (5.4 kilograms). Inflation of stomach by hydrogen gas under full anæsthesia. The effect of the infla-

tion was the same as in the last experiment; only the stomach and upper portion of the small intestines could be distended and further inflation was impossible, as the gas escaped from the stomach as soon as the pressure exceeded one pound (.45 kilogram). A large aspirator needle was pushed through the linea alba into the stomach, and the gas which escaped through it, on being lighted, burned with the characteristic blue flame. After the needle was withdrawn, the inflation was continued to ascertain if the puncture in the stomach would allow the escape of gas into the peritoneal cavity. The inflation was continued until the entire abdomen was distended by the gas. That the distention and tympanites was due to the presence of gas in the peritoneal cavity became evident, as it remained after the stomach had been emptied of its gas, and on percussion it was ascertained that the entire liver dullness had disappeared. The dog recovered without symptoms of peritonitis or any other ill-effects from the experiment.

These experiments demonstrate conclusively that it is more difficult to inflate the alimentary canal from above downwards than from below upwards, as in the living animal I succeeded only in one instance in forcing hydrogen gas from mouth to anus, while in others a degree of force sufficient to rupture the peritoneal coat of the stomach, only effected distention of the stomach and upper portion of intestinal canal. It is evident that great distention of the stomach constitutes an important factor in causing or aggravating intestinal obstruction, as it effects compression which causes impermeability of the intestines, or aggravates conditions arising from an antecedent partial permeability, by producing sharp flexions among the distended coils of the intestines. For diagnostic and surgical purposes the stomach can be readily inflated almost to any extent through a stomach tube, and when it becomes necessary to ascertain the presence of a visceral wound or perforation of this organ, this method of inflation may be resorted to with advantage.

3. Experiments to Determine the Degree of Force which is Necessary to Overcome the Resistance Offered by the Ileo-Cæcal Valve.

Accurate experiments to determine the force required to render the ileo-cæcal valve incompetent by insufflation of air or gas having not heretofore been made, as it is exceedingly important to obtain some accurate information on this subject, the following experiments were made. In all experiments air or hydrogen gas was used. The inflation was made with a rubber balloon. The pressure was esti-

mated either with a mercury gauge or with a manometer, as used by gas-fitters and plumbers. The manometer or mercury gauge was connected by means of rubber tubing with the rectal tube on one side and the rubber balloon on the other. The rubber balloon in which the hydrogen gas was collected held four gallons, and numerous experiments showed that when the gas was forced through the opening of a stopcock, the lumen of which was about the size of a knitting needle, a compression equal to two hundred pounds (91 kilograms) would never register more than three pounds (1.4 kilograms) of pressure. In the living subject the escape of air or gas from the rectum was prevented by an assistant pressing the margins of the anus firmly against the rectal tube.

Experiment 15. Dog, weight thirty-five pounds (16 kilograms). Immediately after death the lower portion of the rectum was isolated and the rectal tube inserted and fixed in its place by tying a string firmly around the rectum. The abdomen was opened and the intestines left *in situ.* The ileum was cut transversely six inches above the ileo-cæcal valve and a glass tube inserted into the distal end, which was also tied in. Hydrogen gas was inflated from a rubber balloon. Under a pressure of three-quarters of a pound (.3 kilogram) the cæcum was dilated, and a moment later the gas escaped from the glass tube and was ignited; the flame remained steady under a pressure of from one-half to three-quarters of a pound (.2 to .3 kilogram).

Experiment 16. Dog, weight twenty pounds (9 kilograms). Same as in the preceding experiment, only that the resistance of the ileo-cæcal valve was overcome under a pressure of one-half pound (.2 kilogram). The distention of colon and cæcum was moderate, and signs of injury to the tunics could not be found in either experiment.

Experiment 17. Dog, weight twenty-three pounds (10 kilograms). In this experiment the abdomen was opened immediately after death, and a large hypodermic needle inserted into the ileum a short distance above the ileo-cæcal valve before the inflation of hydrogen gas was made. A pressure of three-quarters of a pound (.3 kilogram) was sufficient to force the gas through the ileo-cæcal valve and through the needle; the valve remained open under a steady pressure of one-half pound (.2 kilogram).

Having determined that air and gas could be forced beyond the ileo-cæcal valve in dogs under very low pressure, varying from one-half to three-quarters of a pound, I proceeded to test the degree of resistance of the ileo-cæcal valve in the human subject.

Experiment 18. Strong, healthy young man. The subject was placed flat upon his back and hydrogen gas was inflated from a rubber balloon. At first the gas was forced in very slowly under a pressure of one pound and a half

(.7 kilogram), which distended the colon visibly as far as the cæcum. As the distention appeared to remain the same, the pressure was increased to two pounds (.9 kilogram), when suddenly the indicator of the manometer receded to one pound (.45 kilogram), and the umbilical region became prominent and resonant, showing conclusively that the ileo-cæcal valve had been passed and the small intestines were filling rapidly with gas. As soon as the whole abdomen had become distended and tympanitic, the manometer again registered one pound and a half (.7 kilogram) of pressure, and remained at this figure for some time after further inflation was discontinued by turning the stopcock.

Experiment 19. Young man, in good health. Experiment conducted in the same manner as before. After the colon and cæcum had been well dilated the manometer registered two and one-quarter pounds (1 kilogram), and the umbilical region became prominent and resonant. As the inflation advanced the average pressure was one pound and three-quarters (.8 kilogram), and twice it was increased to two and a half pounds (1.1 kilograms), when the patient complained of pain in the umbilical region. As soon as the stopcock was turned the pressure sank to three-quarters of a pound (.3 kilogram).

These two experiments prove that in a normal condition the ileo-cæcal valve in a healthy adult person is overcome by rectal inflation under a pressure of one and a half to two and a quarter pounds (.7 to 1.1 kilograms). This amount of pressure is not sufficient to injure the tunics of a healthy intestine, and in both instances the subjects of the experiments complained but little of the immediate or remote effects of the experiments. As the result of numerous observations, I can state that when the inflation is made slowly and continuously there is less danger of injuring the intestines than when the inflation is made rapidly, or with interruptions. Slow and gradual distention of the cæcum is best adapted to overcome the competency of the ileo-cæcal valve, by effecting diastasis of the margins of the valve. A rubber balloon holding from two to four gallons (10 to 20 litres) recommends itself as the most efficient and safest instrument for making rectal insufflation for therapeutic or diagnostic purposes.

The following experiments were made to determine:

4. The Amount of Pressure Necessary to Force Hydrogen Gas Through the Entire Alimentary Canal by Rectal Inflation.

Experiment 20. Dog, weight thirty-five pounds (16 kilograms). Immediately after death rectal inflation of hydrogen gas was made, and a pressure of one pound (.45 kilogram) sufficed to distend the entire abdominal cavity, and

when a tube was introduced into the stomach and a burning taper applied to its end, a blue flame at once appeared and continued as long as the inflation was kept up under the same pressure.

Experiment 21. Dog, weight twelve pounds (5.4 kilograms). Under ether narcosis rectal inflation of hydrogen gas from rubber balloon. The ileo-cæcal valve offered very little resistance, and as soon as the manometer registered one pound and a half (.7 kilogram) of pressure the gas escaped through the stomach tube which had been introduced previously, and on applying a lighted taper it burned with a continuous flame as long as the inflation was continued.

Experiment 22. Dog, weight twenty pounds (9 kilograms). Experiment and result same as in last; the pressure never exceeded one pound and a half (.7 kilogram).

Experiment 23. Dog, weight nineteen pounds (8.6 kilograms). In this experiment no anæsthetic was used, and in consequence the pressure had to be increased to three pounds (1.4 kilograms) before the gas escaped through the stomach tube. On account of the violent contractions of the abdominal muscles the escape of gas was intermittent, the flame being frequently extinguished by an absence of the gas.

Experiment 24. Dog, weight twenty-one pounds (9.5 kilograms). The animal being completely under the influence of ether the abdomen was opened in the median line, and the ileo-cæcal region made accessible to sight. Hydrogen gas was inflated per rectum, and under a pressure of three-quarters of a pound (.3 kilogram) readily passed the ileo-cæcal valve, and under one pound of pressure it ascended the intestinal canal, and in a few seconds reached the stomach. A tube was introduced into the stomach, and as the gas escaped it was ignited and burned with a steady flame.

Experiment 25. Dog, weight eighteen pounds (8 kilograms). Rectal insufflation of hydrogen gas, the dog being fully under the influence of an anæsthetic. The colon and cæcum were only slightly distended when the gas, under one-quarter of a pound (.1 kilogram) of pressure, passed the ileo-cæcal valve. Under one pound (.45 kilogram) of pressure, the abdomen became uniformly distended and tympanitic, and when a tube was introduced into the stomach the escaping gas was ignited and burned with a steady flame as long as the pressure was continued.

Experiment 26. Dog, weight twenty pounds (9 kilograms). Animal etherized, and when completely relaxed hydrogen gas was inflated per rectum, and passed the ileo-cæcal valve under a pressure of half a pound (.2 kilogram). The stomach became distended under a pressure of one pound and a half (.7 kilogram), and on the introduction of a tube the escaping gas was ignited and burned with a continuous flame as long as the manometer registered half a pound (.2 kilogram) of pressure.

In all animals where the insufflation was not complicated by abdominal section, no unpleasant symptoms followed the experiments. All of the animals recovered as rapidly as after an ordinary ether narcosis. In all of the experiments the pressure fell rapidly after the

ileo-cæcal valve had been opened, but the pressure had again to be increased before the gas reached the stomach. It usually required one-half to one pound more pressure to force gas through the entire alimentary canal than when it was forced only through the ileo-cæcal valve. Whenever it becomes desirable to conduct the hydrogen gas a considerable distance along the intestines, or through the entire alimentary canal, it is exceedingly important to proceed slowly with the inflation, as under slow distention half a pound (.2 kilogram) of pressure will accomplish in time a greater degree of distention than four times this amount of pressure if the force is applied quickly, and only for a short time, and is attended by much less risk of injury to the coats of the intestines. I am quite convinced that in the dog, rectal insufflation of hydrogen gas made under a pressure of one-quarter of a pound, if made very slowly, the abdominal walls being completely relaxed by an anæsthetic, will not only overcome the resistance offered by the ileo-cæcal valve, but will prove sufficient to force the gas through the whole length of the alimentary canal.

I have already sufficiently demonstrated the permeability of the ileo-cæcal valve and the entire alimentary canal in animals and man to rectal insufflation of air and gas, and I shall now endeavor to establish the safety of this procedure as a diagnostic and therapeutic measure by showing:

II. The Resistance of Different Portions of the Gastro-Intestinal Canal to Diastaltic Force.

1. Stomach.

Experiment 27. Large, healthy, adult dog. Experiment made immediately after death. Stomach *in situ.* Œsophagus tied and distention made with a force pump from pyloric orifice, the organ being rapidly dilated with air. When the manometer registered eight and one-half pounds (3.9 kilograms) of pressure, the stomach was distended at least eight times its normal size, when a rent in the peritoneal covering an inch and a half in length parallel to, and near the omental attachment, occurred.

Experiment 28. Middle-aged man, died of sepsis. The whole gastro-intestinal canal showed marked evidences of septic gastro-entero-colitis, the mucous membrane being softened, very vascular, and dotted with numerous hæmorrhagic infarcts. Organ *in situ* inflated with air in the same manner as in last experiment. Longitudinal rupture of peritoneal coat along anterior surface under two and one-half pounds of pressure (1.1 kilograms), and when it was increased to three pounds (1.4 kilograms), the whole thickness of the wall at the lesser curvature ruptured.

2. Small Intestines.

Experiment 29. Subject same as in experiment 28. Lower portion of ileum under five pounds (2.3 kilograms) of pressure, became emphysematous along mesenteric attachment, and ruptured completely as soon as the manometer registered five and three-fourths pounds (2.6 kilograms) of pressure.

Experiment 30. Dog, weight twenty pounds (9 kilograms). Immediately after death the lower part of the ileum, with mesenteric attachment intact, was gradually distended and remained intact until a pressure of ten pounds (4.5 kilograms) was reached, when air escaped between the two serous layers of the mesentery, showing that minute ruptures at numerous points had taken place. When the distention had reached its maximum, the segment of bowel inflated was elongated twice its normal length.

Experiment 31. Upper portion of ileum of same animal when distended to its utmost gave way under a pressure of eight pounds (3.6 kilograms), the peritoneal coat on convex side rupturing to the extent of two inches (51 mm.) parallel to the axis of the bowel.

Experiment 32. The middle portion of the small intestines, when subjected to a pressure of eight pounds (3.6 kilograms), sustained a longitudinal rupture of the peritoneum on convex surface, and the remaining tunics gave way when the pressure was increased to nine pounds (4.1 kilograms).

3. Colon.

Experiment 33. Subject same as experiments 28 and 29. Experiment was made twenty-four hours after death. Colon and cæcum apparently very much softened and mucous membrane in a state of inflammation. One foot (30 cm.) of the transverse colon isolated and gradually distended, when the peritoneal coat along the border of one of the longitudinal bands ruptured under a pressure of two pounds and a half (1.1 kilograms). The peritoneal laceration became very extensive before the remaining tunics ruptured under a pressure of four pounds (1.8 kilograms).

Experiment 34. Dog, weight eighteen pounds (8.2 kilograms). Immediately after death the ileum was tied just above the cæcum, and the inflation made per rectum. Air was pumped in gradually with a force-pump and when the pressure reached ten pounds and a half (4.8 kilograms), air escaped between the peritoneal layers of the meso-colon; at this stage the longitudinal distention of the bowel exceeded twice its normal length.

Experiment 35. Dog, weight twenty-three pounds (10.4 kilograms). Experiment the same as the preceding. Air was pumped in rapidly until the mercury gauge registered ten and a half pounds (4.8 kilograms) of pressure, when the sigmoid flexure on its free surface gave way with a loud report, the rent being about one inch and a half (38 mm.) in length.

Experiment 36. Dog, weight eighteen pounds (8.2 kilograms). Entire colon distended by rectal inflation of air, the ileum being tied just above the ileo-cæcal valve. Under a pressure of six pounds (2.7 kilograms), the peritoneum ruptured in a longitudinal direction, opposite the meso-colon, and the remaining tunics gave way a little later, under the same pressure.

These experiments are of the greatest importance in showing that the pressure which was found necessary to apply in rupturing a healthy intestine, was greatly in excess of that which is required to force air through the ileo-cæcal valve, or even the whole length of the alimentary canal. It only requires from one-quarter of a pound to a pound and a half (.1 to .7 kilogram) of pressure to force air through the ileo-cæcal valve, and from half a pound to two pounds and a half (.2 to 1.1 kilograms) to force it from anus to mouth, while even the weakest portion of the gastro-intestinal canal effectually resisted a distending force of from eight to ten pounds (3.6 to 4.5 kilograms).

The experiments on the human cadaver, where the resisting power of the gastro-intestinal canal to diastaltic force was greatly reduced by ante-mortem pathological changes, show that under such circumstances it would have been safe to resort to inflation, as the pressure required to rupture the colon or small intestines exceeded that which has been found adequate to force air or gas beyond the ileo-cæcal valve, or even the entire length of the alimentary canal. When an intestine is slowly distended to its utmost capacity by inflation of air or gas, and the pressure is maintained uninterruptedly, rupture occurs at one of two points; either a longitudinal laceration of the peritoneal coat takes place on the convex surface of the bowel opposite the mesenteric attachment, or minute ruptures on the mesenteric side give rise to extravasation of air or gas between the two serous layers of the mesentery. In either case, if the pressure is increased, complete rupture takes place at the point where the laceration first commenced.

III. Distention of Gastro-Intestinal Canal by Rectal Insufflation of Hydrogen Gas.

In this section will be found an account of the experiments which were made preliminary to the practical application of the hydrogen gas test as a diagnostic measure in penetrating wounds of the abdomen, and which furnish only so many more demonstrations of the permeability of the ileo-cæcal valve and the entire alimentary canal to rectal inflation of hydrogen gas.

Experiment 37. Dog, weight fifteen pounds (6.8 kilograms). Under ether anæsthesia, hydrogen gas from rubber balloon was slowly forced into the rectum until the entire anterior abdominal wall had become uniformly dis-

tended and tympanitic, when the distended stomach was punctured with a large aspirator needle and gas escaped in a steady stream, which when ignited burned with a continuous flame. After a considerable portion of the gas had been evacuated in this manner the upper abdominal region receded, and the flame was extinguished. The animal recovered without any untoward symptoms.

Experiment 38. Dog, weight seventeen pounds (7.7 kilograms). Without anæsthesia hydrogen gas was inflated per rectum until it escaped through a tube which had been introduced into the stomach. As it escaped from the stomach tube it was ignited and burned with a large blue flame. The abdominal muscles were so rigid that distention was never well marked, and the inflation required a good deal more force than in animals where muscular rigidity had been overcome by an anæsthetic. The dog remained perfectly well after the experiment, and in a few hours the remaining tympanites had disappeared.

Experiment 39. Dog, weight thirty-five pounds (15.8 kilograms). No anæsthetic used. On account of rigidity of abdominal muscles it required persistent efforts to force hydrogen gas from rubber balloon per rectum through the whole alimentary canal. As soon as the stomach had become distended by the gas, the animal vomited; at the same time gas escaped by repeated eructations. The animal manifested no signs of suffering after the experiment.

Experiment 40. Dog, weight twenty-seven pounds (12.2 kilograms). Under anæsthesia hydrogen gas was inflated per rectum until it escaped through tube which had been introduced into the stomach; a lighted taper was applied to the free end of the tube, and the gas ignited and burned with the characteristic blue flame.

Experiment 41. Large Newfoundland dog. Under anæsthesia a duodenostomy was made, and hydrogen gas injected per rectum and ignited as it escaped from a rubber tube, which had been inserted into the distal portion of the bowel through the fistula.

Experiment 42. Adult male; abdominal organs healthy; no anæsthesia. Inflation of hydrogen gas per rectum. The gas was stored in a four-gallon (9 litres) rubber balloon and was forced into the rectum by compression. As the distention progressed the colon could be distinctly mapped out from sigmoid flexure to cæcum by inspection and percussion. As soon as the cæcum had become visibly prominent, a stethoscope was applied over the ileo-cæcal region, and as the valve became incompetent by overdistention of cæcum, a distinct gurgling sound could be heard as the gas entered the ileum. Whenever inflation was arrested the gurgling sound disappeared, but was heard again whenever the ileo-cæcal valve was opened by renewed inflation.

Distention of the small intestines was attended by resonance and prominence of umbilical and hypogastric regions. The incompetency of the ileo-cæcal valve was invariably announced by a reduction in the pressure. The patient complained of a sensation

of distention in the umbilical region and intermittent colicky pains which, however, disappeared completely after a few hours. The pain appeared to be less severe than after similar experiments with inflation of air.

Experiment 43. Young man in comparatively good health. Inflation same as in preceding experiment. Auscultation over ileo-cæcal valve revealed the same sounds as the gas escaped from the colon into the ileum. The sound seemed to vary somewhat according to the size of the opening in the valve and the force used in making the inflation, and always disappeared as the valve closed after suspension of inflation. The colicky pains subsided as the small intestines emptied themselves of their new contents. The assistant who compressed the rubber balloon was always able to announce the beginning of the incompetency of the ileo-cæcal valve, by experiencing a sudden diminution in the pressure.

Experiment 44. Adult male, suffering from gastric catarrh. Hydrogen gas inflation per rectum to extent of causing great distention of abdomen, which caused the hepatic dullness to ascend at least two inches. Auscultatory signs the same. Sharp colicky pains in the umbilical region were relieved by a free escape of gas through rectum.

Experiment 45. Hysterical female. Abdomen flat and dull on percussion from umbilicus to pubes; no resonance over sigmoid flexure. Rectal inflation with hydrogen gas. Compression of rubber balloon corresponding to only one-fourth pound (.1 kilogram) of pressure readily dilated the whole colon, its course being indicated by a distinct prominence and tympanitic resonance from sigmoid flexure to cæcum. Under the same pressure the gas escaped with little or no resistance through the ileo-cæcal valve from the colon into the ileum, the occurrence being attended by the characteristic auscultatory sounds and followed by distention and resonance of space from umbilicus to pubes. Amount of gas inflated about four litres. The patient complained of some pain in the region of the splenic flexure of the colon during the distention of the colon, and later of slight intermittent pain in the region of the umbilicus.

Experiment 46. Middle-aged woman, suffering from retroversion of the uterus. Abdomen flaccid and dull on percussion in the median line from umbilicus to pubes. Rectum distended with hardened fæces. Hydrogen gas inflated in the usual manner. The mercury gauge registered two and a half pounds (1.1 kilograms) of pressure before the gas reached the sigmoid flexure, after this it fell to one pound (.45 kilogram), and the inflation progressed without any further resistance. As soon as the gas passed through the ileo-cæcal valve the pressure fell to three-quarters of a pound (.3 kilogram), and remained so during the inflation of the small intestines, slight variations marking the opening and closing of the ileo-cæcal valve. As the umbilical and hypogastric regions became prominent and tympanitic the patient complained of a griping pain. About eight litres of gas were injected. A few hours after the experiment all symptoms had disappeared.

Experiment 47. Female recently operated on for laceration of perineum. Rectum empty. Abdomen flaccid; umbilical, hypogastric, and right iliac regions dull on percussion. The inflation was made very slowly and the pressure never exceeded one pound (.45 kilogram). As the large intestine became distended the transverse colon came plainly into view. On auscultation over the ileo-cæcal valve the escape of gas into the ileum was marked by a blowing sound, which was increased or diminished in pitch by the degree of pressure. As the lower portion of the small intestines became distended the lower part of the abdomen became prominent and tympanitic, and the patient complained of colicky pains. About three litres of gas were inflated. In half an hour the patient appeared as well as before inflation.

Experiment 48. Middle-aged physician suffering from typhlitis. This was the second attack, and the acute symptoms had subsided. Over the cæcum a circumscribed area of dullness and tenderness. On palpation it appeared as though the swelling were adherent to the anterior abdominal wall. The area of dullness was outlined externally by pencil marks, before inflation was commenced. As the colon became distended under a pressure of one-fourth of a pound (.1 kilogram), the circumscribed, indurated region became more prominent, imparting to the palpating fingers the feeling of hardness, but on percussion it was resonant, showing conclusively that the inflamed and indurated wall of the cæcum had been lifted forward by the pressure of the gas. Under the same pressure the gas escaped in a continuous stream into the ileum, its passage through the ileo-cæcal valve being attended by a well-marked blowing, gurgling sound. The patient felt the entrance of gas into the ileum distinctly, and complained soon after of a slight colicky pain in the umbilical region. The space between umbilicus and pubes, which before inflation was completely dull on percussion, now became more prominent and tympanitic. Only two litres of gas were used in this experiment.

Experiment 49. Young physician in perfect health. Region between umbilicus and pubes perfectly dull on percussion, also left iliac fossa. Inflation of four litres of hydrogen gas under one-third of a pound (.15 kilogram) pressure. The outlines of the distended colon could be clearly seen and marked out by percussion before the gas escaped into the small intestines. The passage of gas through the ileo-cæcal valve was again attended by a well-marked gurgling sound, after which the entire abdomen became prominent and tympanitic. The patient felt a sensation of distention during the inflation of the colon, and as the small intestines became distended, complained of griping pains. Gas escaped freely by eructations and per rectum, which soon relieved the colicky pains in the umbilical region.

Experiment 50. Medical student in robust health. Region from umbilicus to pubes flat on percussion, while the course of the entire colon was tympanitic. Rectal inflation with hydrogen gas. When the resistance of the ileo-cæcal valve was overcome the mercury gauge registered one-half pound (.2 kilogram) of pressure. The passage of gas through the ileo-cæcal valve was attended by a gurgling sound which was heard at some distance by a number of persons present in the room. Later a continuous blowing (almost amphoric)

sound could be heard over the ileo-cæcal valve. The subject of the experiment was conscious of the passage of gas from colon into ileum, and soon after complained of a colicky pain which he referred to the umbilical region. The whole abdomen became uniformly distended and tympanitic on percussion, and the distress caused by the great distention was only relieved by a free escape of gas by eructations and through the rectum. Four litres of gas were used in this experiment.

Experiment 51. Young physician in good health. Rectal inflation of four litres of hydrogen gas under a pressure of only one-third pound (.15 kilogram). Distention of colon well-marked previous to escape of gas through the ileo-cæcal valve. As soon as the gas entered the ileum the middle and lower portion of the abdomen became distended and tympanitic. The inflation was continued until the stomach became distended and gas escaped by eructation. The subject of the experiment complained of quite severe colicky pains as long as the small intestines remained distended by gas.

Experiment 52. The writer of this paper, being desirous of experiencing himself the sensations which would be caused by inflation of hydrogen gas, submitted himself to experimentation under a pressure of one-half pound (.2 kilogram). Nearly six litres of gas were inflated per rectum. The distention of the colon caused simply a feeling of distention along its course, but as soon as the gas escaped into the ileum colicky pains were experienced, which increased as insufflation advanced, and only ceased after all the gas had escaped, an hour and a half later. When the intestines and the stomach had become fully distended, the feeling of distention was distressing, and was attended by a sensation of faintness which caused a profuse clammy perspiration. A great deal of the gas escaped by eructation, which was followed by great relief. The colicky pain attending inflation of the small intestines by air or gas, was evidently caused by increased peristaltic action of the bowels in their attempt to expel their contents, as it always assumed an intermittent type and subsided promptly after the escape of the gas.

In none of these experiments did the pressure in overcoming the resistance offered by the ileo-cæcal valve exceed one pound (.45 kilogram), and often a steady, long-continued pressure of one-fourth or one-third of a pound (.1 to .15 kilogram) sufficed. Every time the ileo-cæcal valve was rendered incompetent by distention of the cæcum, the pressure was promptly diminished owing to the escape of gas from the colon into the ileum. In the experiment where the inflation was made in a case of typhlitis, the ileo-cæcal valve offered no resistance, and the gas escaped freely into the ileum. The valve in all probability had been rendered partially or completely incompetent during the course of local inflammation, or the indurated, thickened walls of the cæcum, when distended during the inflation, were better adapted to effect incompetency of the valve. These

experiments also furnish strong proof of the fact that inflation, to be safe and effective, should be done very slowly under a low, steady pressure, continued only for a short time; and is attended by no risks whatever of rupturing a healthy intestine and, when cautiously practiced, can be resorted to even in cases where the resisting power of the intestinal wall has been diminished by antecedent pathological processes.

As I was searching for an innocuous, non-irritating gas which, when inflated into the gastro-intestinal canal, would escape into the peritoneal cavity in case a wound or perforation existed, and had decided on trying hydrogen gas, it became necessary to study experimentally the effect of this gas on the different tissues of the living body. The numerous inflation experiments on man and dogs have demonstrated the safety of pure hydrogen gas when employed in this manner, as not in a single instance were any immediate or remote toxic symptoms observed which could be referred to absorption of the gas; hence we have the assurance that the inflation of a large quantity of hydrogen gas is unattended by any risk whatever as far as intoxication is concerned. The following experiments also show the innocuity and non-irritating qualities of hydrogen gas when brought in contact with the tissues most susceptible to inflammatory reaction in the living body; at the same time they show that hydrogen gas is removed by absorption in a comparatively short time, when injected into serous cavities or into the subcutaneous connective tissue:

IV. Hydrogen Gas is Innocuous and Non-Irritating when Brought in Contact with Living Tissues and is Promptly Removed by Absorption.

1. Peritoneal Cavity.

Experiment 53. Dog, weight forty-five pounds. A circumscribed spot to the right of the linea alba was shaved and thoroughly disinfected, and through this space a well disinfected, medium sized trocar was plunged into the peritoneal cavity. To the cannula of the trocar the rubber tube of the inflation balloon charged with hydrogen gas was attached, and the whole peritoneal cavity filled with gas by compressing the balloon. About four litres of gas were injected. No gas escaped upon the withdrawal of the cannula and the puncture was sealed with cotton and iodoform collodium. The animal appeared to suffer but little pain, and the next day the tympanites had disappeared and the dog was as frisky and lively as before the inflation. Two

days after the experiment was made the dog was killed and the peritoneal cavity carefully examined. Not a trace of the gas remained and the peritoneum throughout presented a normal appearance.

2. Pleural Cavity.

Experiment 54. Dog, weight twenty-five pounds. After thorough disinfection, an aseptic hollow needle was inserted between the seventh and eighth ribs in the axillary line into the left pleural cavity, and hydrogen gas from rubber balloon forced through it until the pleural cavity was thoroughly distended. On making a physical examination of the chest at this time the apex of the heart was found to the right of the sternum; vesicular breathing on left side absent; abnormal resonance on percussion of this side. The respirations became superficial and greatly increased in frequency. On withdrawing the needle no gas escaped externally, but a circumscribed subcutaneous emphysema which appeared, showed that some of the gas had escaped through the puncture in the pleura into the subcutaneous connective tissue. Twenty-four hours after the inflation the dog appeared to be in perfect health. The normal relations in the chest had become restored and the subcutaneous emphysema was less extensive. The animal was kept under observation for a considerable length of time, but at no time could symptoms of pleuritis be detected.

3. Subcutaneous Cellular Tissue.

Experiment 55. Old dog, weight forty-three pounds. A small, perfectly aseptic trocar was inserted through the skin into the loose cellular tissue in the right inguinal region, and through the cannula two litres of gas were injected, the gas distributing itself through the loose connective tissue over a large surface of the body. Upon the withdrawal of the cannula the puncture was hermetically sealed with iodoform collodium and cotton. The subcutaneous emphysema disappeared completely in forty-eight hours, and no traces of inflammation could be found at the point of puncture, or at any place where the gas had come in contact with the tissues.

Experiment 56. Dog, weight twenty-five pounds. Subcutaneous inflation of two litres of hydrogen gas through the cannula of a small trocar into the left side of the chest. The subcutaneous emphysema reached from the clavicle and axilla on that side to the crest of the ilium, the gas at some points elevating the skin at least four inches from the subjacent tissues. The gas was absorbed somewhat more slowly than in the preceding experiment, but three days after the inflation no trace of emphysema could be detected, and the subcutaneous connective tissue was as pliable and movable as before the inflation.

V. Rectal Insufflation of Hydrogen Gas in the Diagnosis of Penetrating Gunshot Wounds of the Abdomen.

In these experiments the animals were strapped on one of Pasteur's operating tables. Abdomen shaved, and after complete

etherization the shooting was done at short range with a thirty-two calibre revolver. Inflation of hydrogen gas was practiced immediately after the shot was fired, and after its diagnostic value was carefully studied, the abdomen was opened and its contents examined for visceral injuries. In all cases where the colon was perforated, inflation could be done under very slight pressure, as the gas readily escaped into the peritoneal cavity, and from there through the bullet wound in the abdominal wall, where it was ignited as it escaped. As it is not my object at present to give the result of the operative treatment, the experiments will only be described in reference to diagnosis as verified by abdominal section; but in every case an attempt was made to save the life of the animal by operative treatment, and in a few instances the efforts were rewarded by success.

Experiment 57. Dog, weight thirty pounds. The abdomen was opened by an incision through the linea alba and a coil of the small intestine was drawn forward into the wound, and an incision half an inch (13 mm.) in length was made on the convex side and the intestine returned. A small glass tube was inserted into lower angle of wound, and the rest of the wound closed by sutures. About two litres of hydrogen gas were inflated per rectum, when the gas escaped through the glass tube, and when ignited burned with a continuous steady blue flame as long as the inflation was continued. The wound was opened and a small quantity of gas was found in the peritoneal cavity. The whole intestinal tract below the visceral wound was found moderately distended by gas, while above the wound the intestine was normal in size.

Experiment 58. Dog, weight fifteen pounds. When the dog was completely under the influence of ether, hydrogen gas was forced from anus to mouth, and while the abdomen was still moderately distended the animal was shot in the abdomen, the bullet being directed transversely from the point of entrance on the side of the abdomen two inches (5 cm.) to the right of the median line, and on a level with the umbilicus. On appliying a lighted taper to wound of entrance, and compressing the abdomen, hydrogen gas escaped and was ignited. When the inflation was resumed the gas burned with a continuous flame at the wound of entrance. The abdomen was then opened and two perforations in the stomach were found, one on the anterior surface near the pylorus, and the other on posterior surface at the cardiac extremity, about an inch above the omental attachment. The distention of the stomach by hydrogen gas had brought this organ within range of the track of the bullet.

Experiment 59. Dog, weight twenty pounds. Under complete anæsthesia the animal was shot in the abdomen, the bullet taking the same direction as in the previous experiment, only that the track was about an inch (2.5 cm.) above the umbilicus. Immediately after the shooting hydrogen gas was

inflated per rectum, and its presence in the abdominal cavity became evident by a marked tympanites, absence of liver dullness, and later by a localized emphysema around the wound of entrance. As the pressure was continued bubbles of gas escaped, and on applying a lighted taper, ignited with a feeble explosive report. The abdomen was opened, and the stomach showed two perforations, one just above the omental attachment near the pylorus, and the other on the same level at the cardiac extremity. Little hæmorrhage, and no extravasation of contents of stomach.

Experiment 60. Dog, weight thirty pounds. Animal anæsthetized and shot in abdomen at a range of two feet; wound of entrance two inches to the right of, and on a level with the umbilicus. Wound of exit one inch above the middle of left crest of ilium. Inflation of hydrogen gas per rectum soon caused extensive tympanites, and as but little force had been used, the conclusion was drawn that some part of the descending colon had been injured. As the gas did not readily escape through the bullet wounds, a small cannula was inserted into the abdominal cavity through the wound of entrance, when the gas escaped freely and was ignited. On opening the abdomen examination revealed the following visceral injuries: Two perforations in the descending colon; four in the ileum, within a distance of ten inches of the ileo-cæcal valve; eight in the upper part of the ileum, within the space of one foot (30.5 cm.) of the intestine. The mesentery was perforated at three points, and a number of mesenteric vessels of considerable size were severed, which gave rise to profuse hæmorrhage.

Experiment 61. Large coach dog. The animal was completely etherized and shot in the abdomen at close range. Wound of entrance midway between linea alba and vertebral column on left side, a little below the level of the umbilicus; wound of exit close to the last lumbar vertebra over crest of ilium on opposite side. Rectal inflation of hydrogen gas under slight pressure at once produced diffuse tympanites, and the gas escaped freely through wound of entrance, where it was ignited and burned with a large steady blue flame as long as the inflation was continued. On opening the abdomen gas escaped, but inspection showed that the small intestines contained no gas, a condition which pointed to the colon as the seat of perforation. One perforation was found in the anterior wall of the sigmoid flexure, and two perforations in the cæcum. In the small intestines two perforations were found in the ileum near the cæcum, and three in the upper portion of the jejunum. Among the other organs injured were the spleen, and the receptaculum chyli; a number of perforations were found in the mesentery.

Experiment 62. Large dog. Profound ether narcosis. Shot in the abdomen, the bullet entering on a level with the umbilicus and about one inch to the left of the median line. Point of exit two inches from spinal column, and a little above the lower border of the chest. On inflating the rectum with hydrogen gas, hardly any force was required to distend the abdomen, and for this reason it was believed that the colon in some part of its course had been injured. Gas escaped readily through the wound of entrance, where it was lighted and burned with the characteristic blue flame. The abdomen when

opened was found almost completely filled with blood. The source of this profuse hæmorrhage was the right kidney which showed a perforation through the centre. An examination of the gastro-intestinal canal revealed two perforations of the cæcum, and five, of the small intestines. After passing through the kidney the bullet perforated the diaphragm, traversed the pleural cavity, and escaped through the chest wall two inches (5 cm.) to the right of the spine.

Experiment 63. Old dog, weight thirty-five pounds. Thoroughly etherized and shot in the abdomen, the bullet entering three inches (7.6 cm.) to the right of, and an inch and a half (3.8 cm.) below the umbilicus, passing almost transversely through the abdominal cavity and escaping at a corresponding point on left side. Inflation of hydrogen gas was attempted, but failed on account of the apparatus being out of order. The abdomen was opened and no gas was found even in the colon. Twelve perforations of the small intestines were found, and a number of perforations of the mesentery, which had caused profuse hæmorrhage.

Experiment 64. Large, black dog. Etherized and shot in the abdomen; wound of entrance three inches (7.6 cm.) to the right of, and an inch and a half below the umbilicus; wound of exit near a corresponding point on opposite side, the bullet taking nearly a transverse course. Rectal inflation of hydrogen gas gave a prompt positive result. The abdomen was opened and five perforations of small intestine were found, besides laceration of thoracic duct, and a number of perforations in mesentery. Colon and small intestine below the lowest point of perforation contained gas, while above the lowest perforation the bowel contained no gas.

Experiment 65. Dog, weight twenty-five pounds. Under full anæsthesia the animal was shot in the abdomen, the bullet passing in a nearly transverse direction through the abdominal cavity an inch and a half below the umbilicus from point of entrance; wound of exit midway between linea alba and spine. Rectal insufflation of hydrogen gas made under very low pressure, led to rapid distention of the abdomen, an occurrence which furnished strong evidence that the gas had escaped through a perforation in the colon into the peritoneal cavity. The gas escaped in bubbles through the wound of entrance, and when a lighted taper was held near the wound, it burned with a jet varying in size. On opening the abdomen gas escaped from the peritoneal cavity; small intestines empty, and only a small amount of gas in the colon. The following intra-peritoneal injuries were found: Four perforations of the duodenum, two of the jejunum, and one of the cæcum; also a perforation nearly through the centre of the left kidney, laceration of the receptaculum chyli, and a number of perforations in the mesentery. The bullet was found between the left kidney and the abdominal wall.

In all of these experiments the bullet was fired through the abdomen from side to side transversely, or somewhat obliquely, directions which invariably brought into the track of the bullet a number of intestinal coils, and often the colon. In the two experi-

ments where the track of the bullet was a little higher up, the intestines escaped, but the stomach showed two perforations, one near the pyloric, and the other near the cardiac extremity. Rectal insufflation of hydrogen gas proved an infallible test in every instance, except in the case where it failed on account of the inflation apparatus being out of order. Contrary to the experience of other experimenters, I found that fæcal extravasation does not uniformly take place soon after gunshot wounds of the intestines; in the cases where I observed it, some part of the colon had been wounded. Intestinal inflation does not, therefore, tend to increase the frequency of this occurrence, and must, on this account, be looked upon as a harmless measure.

Inflation, as a preliminary measure, greatly expedites the first step in the operation of abdominal section in cases where the intestine has been perforated or injured, as the gas which escapes into the peritoneal cavity separates the intestines from the anterior abdominal wall, and the incision can be made safely and rapidly without fear of wounding the intestines. Penetrating wounds of the abdomen, where the course of the bullet is in an opposite direction to that which has been described in the preceding experiments, that is, in an antero-posterior direction, may not implicate the intestines at all; or if visceral injury is inflicted, it is more likely that only a single perforation exists, and never does the surgeon meet with such a multiplicity of lesions as have been cited above. Unless the surgeon can ascertain beforehand, that in a case of penetrating wound of the abdomen an injury to some portion of the gastro-intestinal canal exists, the very means which he resorts to in making an anatomical diagnosis is often an imminent source of danger, as only too often he may have to examine every inch of the gastro-intestinal canal for this purpose, a procedure which is always attended by great risk to life. If by such a simple and harmless procedure as insufflation of hydrogen gas, he can satisfy himself that the gastro-intestinal canal is perforated, the course to pursue becomes clear—to open the abdomen, *seek for the perforation until he finds it*, and adopt proper treatment for the visceral injury.

Cases have also happened in which the operator opened the abdomen, sought for, found and treated one or more perforations and, on making the autopsy a day or two later found, to his great chagrin and sorrow, a perforation which he had overlooked at the

time of operation. It seems to me that in cases in which any doubt exists as to the integrity of the remaining portion of the intestinal canal, after closing one or more perforations, it would be advisable to search for additional perforations by resorting again to slow and careful inflation before the abdominal wound is closed. If no other perforations exist the gas will be confined to the interior of the gastro-intestinal canal, and if the stomach or intestines at some point difficult of access are injured, the leakage of gas through the perforations will lead the surgeon to the wound.

In the practical application of rectal insufflation of hydrogen gas, as a means of diagnosis in penetrating wounds of the abdomen, the field of possible operation should be carefully prepared by shaving and disinfection before inflation. After thorough disinfection of the external wound or wounds, and the field of operation, the patient should be placed thoroughly under the influence of an anæsthetic for the purpose of relaxing the abdominal muscles, which greatly facilitates the inflation.

In the absence of a Wolf's bottle, hydrogen gas can be readily generated in a large wide-mouthed bottle into which a small handful of chips of pure zinc is placed. The mouth of the bottle is closed with a cork with two perforations, through which two glass tubes are inserted, one for the purpose of pouring in water and sulphuric acid, and the other, which should be bent nearly at right angles, for leading away the gas. This glass tube and a rubber balloon with a capacity of sixteen litres of gas are connected by means of a rubber tube. In from five to ten minutes the requisite amount of gas can be generated and everything is ready for the inflation. The rubber tube connecting the balloon with the rectal tip of an ordinary syringe should be interrupted by a stop-cock, so that the escape of gas can be prevented whenever inflation is temporarily suspended. The return of gas along the sides of the rectal tip can be readily prevented by an assistant pressing the anal margins firmly against it.

The inflation must always be made slowly, as long continued, uninterrupted pressure accomplishes most effectually lateral and longitudinal dilatation of the cæcum; conditions which render the ileo-cæcal valve incompetent, and which must be secured before inflation of the small intestines is possible, The entrance of gas from the colon into the ileum is always attended by a diminution of

pressure, and its occurrence can invariably be recognized by a gurgling or blowing sound over the ileo-cæcal valve, sometimes sufficiently loud to be heard at some distance.

If, after inflation, abdominal distention and tympanites be from the very first diffuse, and liver dullness has disappeared, it is a certain indication that they are due to the presence of gas in the peritoneal cavity, and not to distention of the gastro-intestinal canal. If, on the other hand, the distention and tympanites follow the course of the colon, and after the entrance of the gas through the ileo-cæcal valve, are circumscribed and limited to the umbilical and hypogastric regions, and gradually extend to the upper portion of the abdomen, *and the liver dullness is displaced upwards*, they are in all probability caused by a gradual and successive inflation of the intact bowel in an upward direction.

In some penetrating wounds of the abdomen it is difficult, if not impossible to follow the course of the bullet through the abdominal wall with a probe or finger, on account of the relative change of position of the different layers of tissues in the track of the bullet, obliterating the canal; but even in these cases a moderate distention of the peritoneal cavity by an accumulation of gas outside of the intestines, will force bubbles of gas through the tortuous canal. By this sign the surgeon may know positively that some portion of the gastro-intestinal canal has been perforated; and in order to prove that the bubbles which escape are part of the hydrogen gas which has been inflated, he applies a lighted match or taper. If it is hydrogen gas it will ignite with a slight explosive report, and burn with a characteristic blue flame. The burning of the escaping hydrogen gas on the surface of the external wound is a most effective means in securing for the wound an aseptic condition, and on that account, the escaping gas should be lighted, both for diagnostic and therapeutic purposes, in all cases in which rectal insufflation of hydrogen gas reveals the presence of visceral injuries of the gastro-intestinal canal.

As hydrogen gas from its low specific gravity will always occupy the highest space in a cavity partially filled with fluids, it is necessary to place the external abdominal wound in such a position that blood or any other fluid that may be present in the abdominal cavity will not interfere with its ready escape. If the wound is anterior

the patient must be placed in the dorsal position; if lateral, on the opposite side, during the inflation. If during inflation, early and diffuse tympanites takes place, it speaks in favor of perforation of the colon.

Should the external wound prevent the escape of gas from the peritoneal cavity, by sliding of the different layers of tissue of the wound in the abdominal wall, or by the presence of a coagulum in the track made by the bullet, it becomes necessary to secure a sufficient degree of patency of the wound for the escape of gas, by careful probing or the removal of coagulated blood. The finding of perforations is also greatly facilitated by inflation, as the bowel below the lowest perforation will always be found at least slightly dilated by gas. If this perforation is now closed and additional perforations are suspected to exist, the inflation can be repeated, and the bowel will again become distended as far as the next perforation, and this process can be repeated until the entire intestinal canal has been examined. By searching for leaking points in this manner, but little manipulation of the intestines becomes necessary, and thus one of the great sources of danger in the operative treatment of wounds or perforations of the gastro-intestinal canal is avoided.

The moderate distention of the intestines left after treating the visceral wounds, never interfered with the return of the intestines into the abdominal cavity or the closure of the external wound in any of the experiments; and the numerous observations made in reference to the disappearance of the gas by absorption, or escape through the natural outlets, are conclusive in showing that the distention due to the presence of the gas disappears in a remarkably short time. It can therefore be safely stated that rectal insufflation of hydrogen gas in the diagnosis and treatment of penetrating wounds of the abdomen, does not interfere with an *ideal* healing of the visceral and laparotomy wounds.

After a careful study of the subject of rectal insufflation of hydrogen gas in its various aspects, I do not hesitate to recommend its adoption in practice as an infallible diagnostic test in demonstrating the existence of a wound of the gastro-intestinal canal in penetrating wounds of the abdomen, or perforations from any other cause, without resorting to an exploratory laparotomy.

In conclusion I beg leave to submit the following propositions:

1. The entire alimentary canal is permeable to rectal insufflation of air or gas.

2. Inflation of the entire alimentary canal from above downwards through a stomach tube seldom succeeds, and should therefore only be resorted to in demonstrating the presence of a perforation or wound of the stomach, and for locating other lesions in the organ or its immediate vicinity.

3. The ileo-cæcal valve is rendered incompetent and permeable, by rectal insufflation of air or gas under a pressure varying from one-fourth of a pound to two pounds.

4. Air or gas can be forced through the whole alimentary canal from anus to mouth, under a pressure varying from one-third of a pound to two pounds and a half.

5. Rectal insufflation of air or gas to be both safe and effective must be done very slowly and without interruptions.

6. The safest and most effective rectal insufflator is a rubber balloon large enough to hold sixteen litres of air or gas.

7. Hydrogen gas should be preferred to atmospheric air or other gases for purposes of inflation in all cases where this procedure is indicated.

8. The resisting power of the intestinal wall is nearly the same throughout the entire length of the canal, and in a normal condition yields to diastaltic force of from eight to twelve pounds of pressure. When rupture takes place it either occurs as a longitudinal laceration of the peritoneum on the convex surface of the bowel, or as multiple ruptures from within outwards, at the mesenteric attachment. The former result follows rapid, and the latter slow inflation.

9. Hydrogen gas is devoid of toxic properties, non-irritating when brought in contact with living tissues, and rapidly absorbed from the connective tissue spaces and all of the large serous cavities.

10. The escape of air or gas through the ileo-cæcal valve from below upwards is always attended by a blowing or gurgling sound, heard most distinctly over the ileo-cæcal region, and by a sudden diminution of pressure.

11. The incompetency of the ileo-cæcal valve is caused by a lateral and longitudinal distention of the cæcum, which mechanically separates the margins of the valve.

12. In gunshot or punctured wounds of the gastro-intestinal canal, insufflation of hydrogen gas enables the surgeon to demonstrate positively the existence of the visceral injury, without incurring the risks and medico-legal responsibilities incident to an exploratory laparotomy.

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